EFFECTIVE 2018-2023

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Prepared by the Washington Emergency Management Division

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Overview

The Washington State Enhanced Hazard Mitigation Plan – Risk Assessments includes those chapters that meet Element B of the Federal Emergency Management Agency requirements for state mitigation plans. These hazard profiles are overviews of what best available science and data indicate are the areas and populations most at-risk to a given natural or man-made hazard. The hazards included in this document are those identified by the Washington State Hazard Mitigation Workgroup as most significant for Washington State, and include:

- Agricultural Disease Outbreak
- Avalanche
- Climate Change
- Coastal Hazards
- Dam Failure
- Drought
- Earthquake
- Flood
- Hazardous Materials
- Landslide
- Public Health
- Severe Weather
- Terrorism and Cyber-Terrorism
- Tsunami
- Volcano
- Wildfire

Due to the scale of analysis, it is noted that these risk assessments are useful for understanding general trends and facts about natural hazard type, location, frequency, and probability. To understand local conditions, additional ground-truthing and a deeper level of analysis is necessary. Also, due to data limitations, specific exposure numbers should be treated as estimates, and will be continually refined as data is improved.

This document includes discrete chapters for each hazard, but begins with an overview of the technical methodology for the natural hazards. Please reference this section when a natural hazard chapter refers to the “technical appendix.”

How to this use Document

Figures in this plan are numbered using a letter (e.g. V for Volcano) followed by a number. Each section begins numbering figures at “1.”

Maps and analyses were developed using the methodology laid out in the Risk Assessment Approach chapter. Natural Hazards chapters were developed by the University of Washington Institute for Hazard Mitigation Planning and Research, in close cooperation with the Hazard

Mitigation Strategist at Washington Emergency Management and subject matter experts identified in each relevant state agency.

Washington State Natural Hazard Risk Assessment Approach

This risk assessment adopts a holistic view of risk. Traditional risk assessments and tools often address one hazard at a time, and consequently target regions most vulnerable to the one particular hazard; areas subject to multiple hazards, however, are not considered.

The Washington State Risk Index used here adopts a multi-hazard view of risk, combining the natural hazards with socio-economic factors, to create a holistic understanding of the risk faced by communities. This analytical approach is similar to the ongoing initiative by Federal Emergency Management Agency (FEMA) at the national level to create a National Risk Index. The National Risk Index (NRI) incorporates data on social vulnerability, built environment, community resilience, and natural hazards to create a baseline of natural hazards risk for U.S. at the county and census tract level.

The Washington State Risk Index (WaSRI) adopts an analytical approach similar to the National Risk Index with modifications in variable selection and statistical methods to better reflect local priorities and concerns. The risk index is based on spatial overlays of the hazard zone with area, population distribution, vulnerable population distribution, built environment, critical infrastructure facilities, State facilities (owned and leased), and first responder facilities (fire stations, law enforcement buildings, and EMS). The proportional exposure along each of these dimensions were combined to created hazard risk indices for each county. The county indices were aggregated to create the Washington State Hazard Risk Index for each of the ten natural hazards listed earlier.

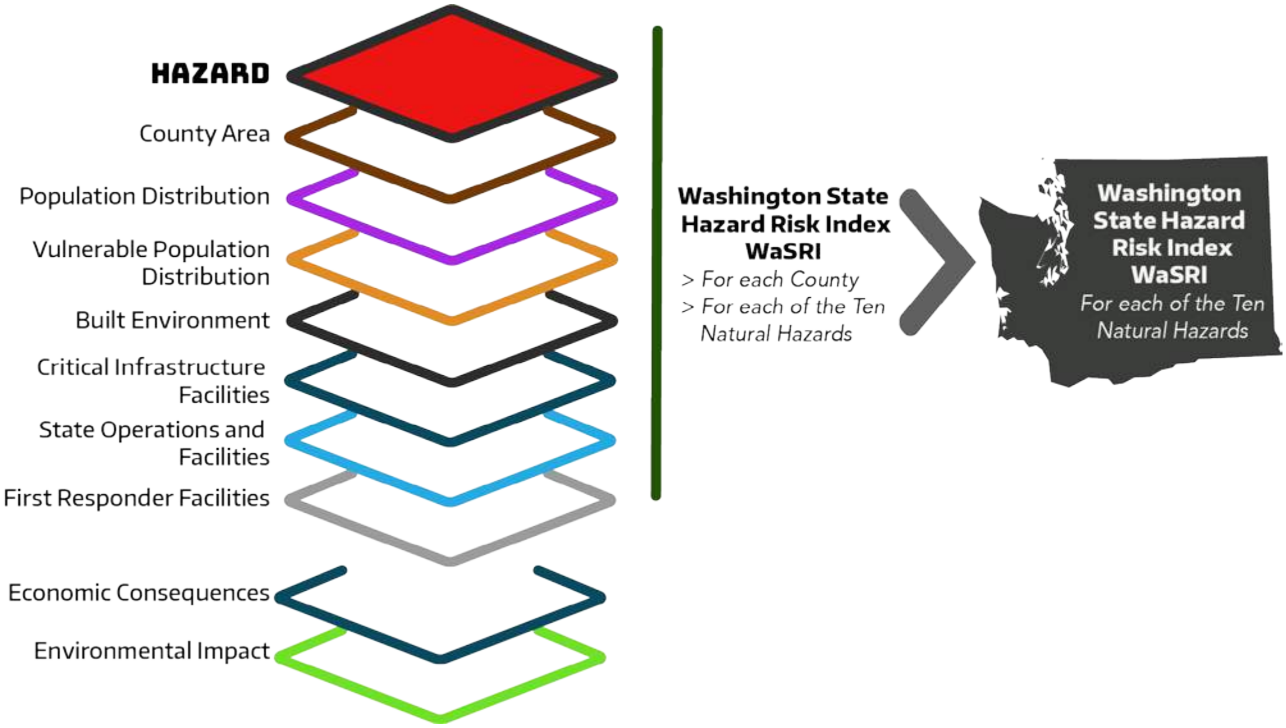

FIGURE TA 1: RISK INDEX CREATION METHODOLOGY

Assessment of economic consequences and environmental impacts were also conducted but were not included in the construction of the index due to methodological limitations as explained in each of the respective hazard sections. The key exposure assessments for each natural hazard include:

1. Area Impacted
2. Population
3. Vulnerable Population
4. Built Environment
5. Critical Infrastructure
6. State Operations and Exposure Facilities
7. First Responder Facilities
8. Economic Consequences
9. Environmental Impacts

Area Impacted

County area exposed to natural hazard risk is estimated by overlaying the hazard area map with the county map to estimate the percentage area exposed to the natural hazard in each county. County maps were projected in ESRI ARCMAP© software utilizing the Lambert Conformal Conic projection coordination system - NAD1983 HARN State Plane Washington South FIPS 4602 Feet. The hazard layers were also re-projected into the same geographic projection to ensure accurate estimation.

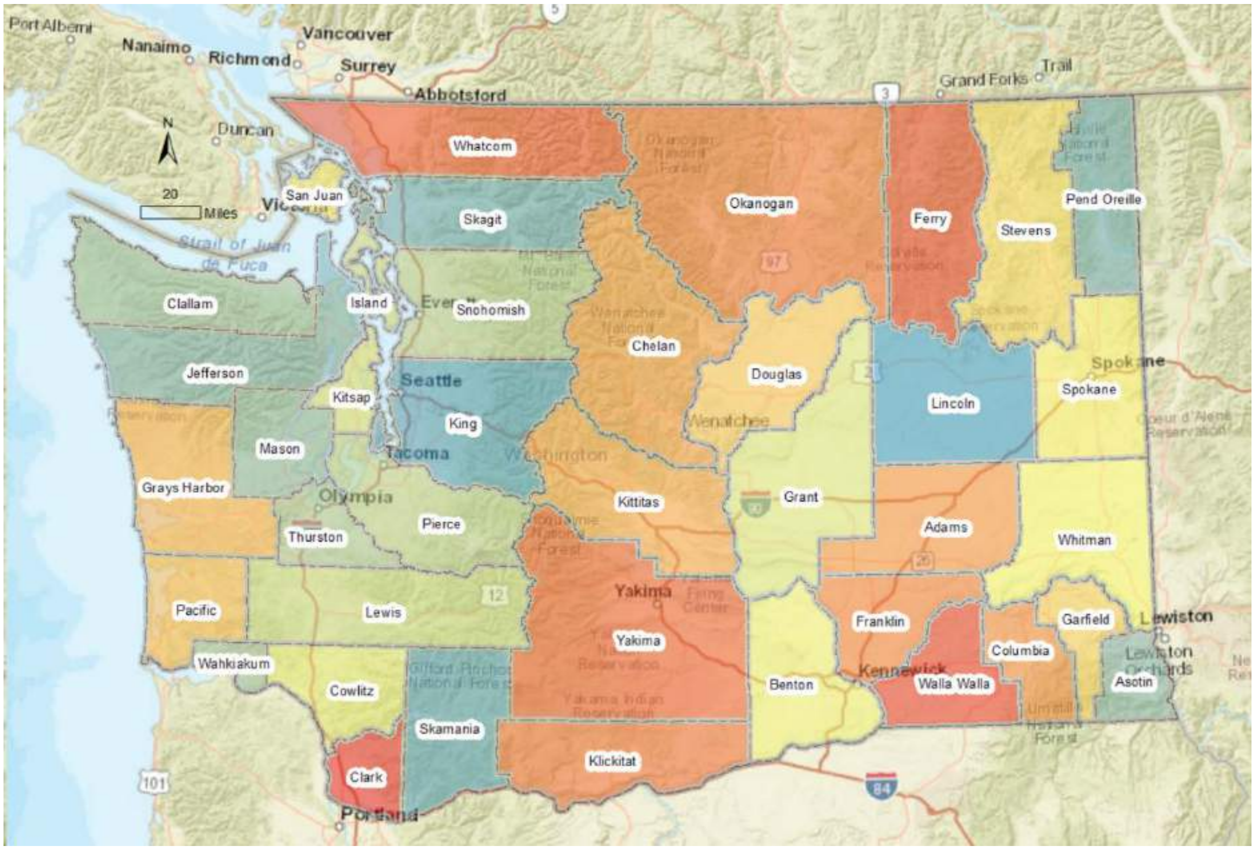

FIGURE TA 2: WASHINGTON COUNTIES

Population

Population exposure to earthquake hazard is estimated by overlaying the hazard layer (medium or higher rank) over the 2011 developed areas derived from the land cover database. The 2017 estimated population for all census tracts was allocated to respective urban areas and the overlap with hazard exposure is estimated using spatial analysis in Geographic Information System (GIS).

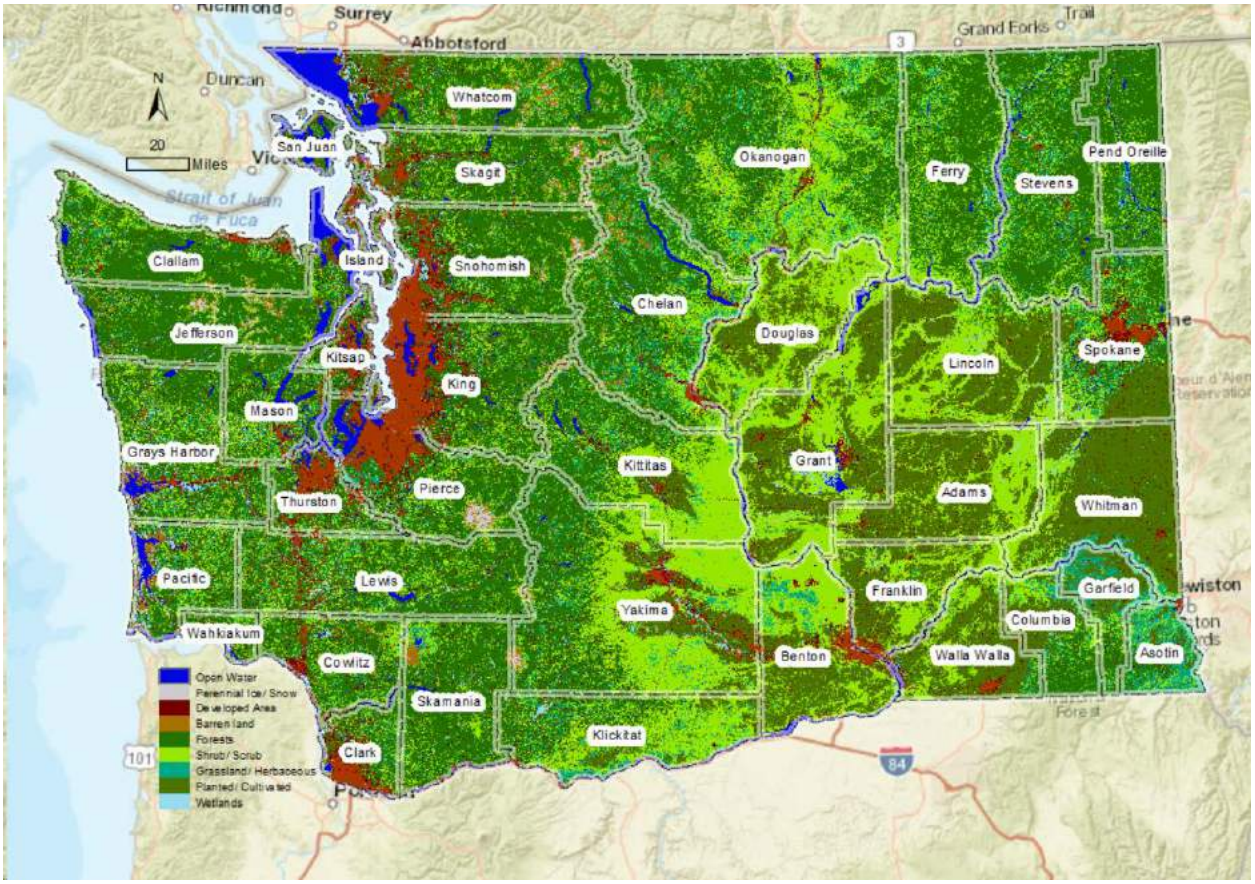

FIGURE TA 3: NATIONAL LAND COVER DATABASE 2011 (SOURCE: WWW.MRLC.GOV)

Vulnerable Population

Social vulnerability examines the differential impact of hazards on society based on existing socio-demographic conditions and community characteristics. A number of social vulnerability Indices have been used by researchers as tools for assessing differences across communities that influence their capacity to prepare for, respond to, and recover from hazards. As part of this risk analysis, a modified version of social vulnerability index based on the methodology developed by ATSDR’s Geospatial Research, Analysis & Services Program (GRASP) was utilized. This risk analysis utilizes the following 15 variables from 5-year ACS estimates (2012-2016):

- Percentage of persons below poverty
- Percentage of civilians unemployed
- Per-capita income

- Percentage of persons (25+) with no HS
- Percentage of persons aged 65 and older
- Percentage of persons aged 17 and younger
- Percentage of civilian non-institutionalized population with a disability
- Percentage of minority race (non-whites)
- Percentage of persons (age 5+) who speak English “less than well”
- Percentage of housing in structures with 10 or more units
- Percentage of mobile homes
- Percentage of occupied housing units with more people than rooms
- Percentage of households with no vehicle
- Percentage of persons in institutionalized group quarters
- Percentage of persons with health insurance

These were combined into an Index of Social Vulnerability with equal weights, that is each variable was given equal importance and not statistically weighted. While the quality of the estimates for individual variables may vary (differences in the margins of error for sampling, for example), the 5-year ACS data was used because it is the only census product providing the detailed data required in understanding social vulnerability. The ACS samples 20% of the population every year, so the 5-year estimates represent the best available data on socioeconomic attributes. The margins of error increase as scale decreases (error larger at block group than tract, for example). This precludes the downscaling of the index below a census tract level because in some instances, the margins of error are greater than the values reported for the individual variable. The resulting estimates are categorized into 5 classes (1-low to 5-high) based on z-score transformation (standard deviations from the mean). The overall county index for social vulnerability is the arithmetic mean of the social vulnerability estimates for each tract.

Built Environment

The built environment exposure to natural hazards is calculated using the general building stock data (2014) provided by FEMA that contains the building values for all structures in the census tracts. General building stock values used in this analysis are the total structure value of all buildings (except agricultural) in each census tract in 2014 dollars. Building values for all occupancy types were summed for each census tract using only structure values (not content values) and assigned to the developed areas within each tract. These maps were then overlaid on the hazard layer to estimate the general building stock value within hazard exposure areas. Individual tract level estimates were aggregated to create the county level estimates.

Critical Infrastructure Exposure

Location of 12 critical infrastructure facilities was mapped for the whole state. The following facilities were identified from the Homeland Security Foundation Level Database (HIFLD) for critical infrastructure analysis:

1. Airports (23)
2. Communication (16097)
3. Dams (268)

4. Education Facilities (5331)
5. Electric Substations (1392)
6. Hospitals (147)
7. Power Plants (146)
8. Public Transit Stations (60)
9. Railroad Bridges (1619)
10. Railway Stations (317)
11. Urgent Care Facilities (113)
12. Weather Radar Stations (2)

This data was overlaid with the hazard exposure layer to identify facilities located in natural hazard areas. This analysis is limited to point data and not critical infrastructure represented by a line such as roads and rail corridors. These networks will also be impacted by natural hazard events but due to data limitation they have not been included in this analysis.

State Operations and Facilities Exposure

The list of state owned (9415) and leased facilities (1039) was obtained from 2017 Facilities Inventory System Report produced by Office of Financial Management. These facilities were geo-located based on the addresses provided in the facilities inventory report and then overlaid with hazard layer.

First Responder Facilities Exposure

Locations of fire stations, law enforcement buildings, and emergency medical stations in the State were identified from the Homeland Security Foundation Level Database (HIFLD). Using ESRI ArcMap geocoding services 1,268 fire stations, 332 law enforcement agencies, and 1,162 EMS stations (including those co-located with fire stations) were located on the State map.

Economic Consequences

The economic activity data was derived from National Association of Counties. This dataset provides the county level estimates of Gross Domestic Product (GDP) for 2016.[1] The Washington State Hazard Risk Index for each hazard was compared with the county GDP to assess the possible economic impacts.

County GDP 2016 Data	
County	**GDP 2016 (in Mil.)**
Adams	$746.07
Asotin	$618.43
Benton	$10,627.85
Chelan	$4,363.01
Clallam	$2,573.06

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[1] http://explorer.naco.org

County GDP 2016 Data	
County	**GDP 2016 (in Mil.)**
Clark	$18,682.64
Columbia	$144.20
Cowlitz	$4,474.88
Douglas	$1,037.39
Ferry	$198.13
Franklin	$3,356.16
Garfield	$97.44
Grant	$3,803.65
Grays Harbor	$2,237.44
Island	$2,796.80
Jefferson	$867.23
King	$230,344.61
Kitsap	$12,082.18
Kittitas	$1,566.21
Klickitat	$1,004.05
Lewis	$2,573.06
Lincoln	$347.25
Mason	$1,566.21
Okanogan	$1,678.08
Pacific	$637.45
Pend Oreille	$354.63
Pierce	$41,280.80
San Juan	$602.88
Skagit	$5,705.48
Skamania	$218.04
Snohomish	$39,378.97
Spokane	$24,723.73
Stevens	$1,111.56
Thurston	$12,865.29
Wahkiakum	$93.41
Walla Walla	$2,908.67
Whatcom	$10,068.49
Whitman	$2,237.44
Yakima	$10,404.10

Risk to Environment

To assess the risk to environmental resources, the spatial land cover mapped data was overlaid with the hazard layer. Forests, scrubland, wetland, and cropland areas were identified as environmentally critical areas. The overlap between these areas of ecological importance and hazard areas was analyzed through spatial analysis in GIS software.

Agricultural Disease Outbreak Hazard Profile

Risk Summary

Frequency – Minor animal/crop/plant disease and infestation outbreaks occur annually in Washington. The potential for severe outbreak in our state is high.

People - The population affected in an animal/crop/plant disease and infestation outbreak in the state could affect more than 1,000 people dead or injured.

Property – Property damage could be in excess of $1 billion dollars in the event of a catastrophic animal/crop/plant disease and infestation outbreak.

Economy – An outbreak could cost our state tens-to-hundreds of millions of dollars directly and indirectly. International embargos could last years and take decades to recover.

Environment – An animal/crop/plant disease and infestation outbreak can be expected to exceed 10 to 20 percent effect of a species or habitat, particularly domesticated species.

State operations and facilities – No significant impacts.

First responders – No significant impacts.

Public confidence – In agriculture, consumer perception of safety and wholesomeness of food and food products often drives the market. In 2003, one cow was found in Washington with Bovine Spongiform Encephalopathy (BSE or “mad cow” disease). The beef market for the United States dropped from 18 percent of the world market to 2 percent of the market.

Hazard assessment – Agriculture is one of our state’s largest industry. An animal disease, crop disease, pest infestation or food safety outbreak can occur at any time. Animal and crop diseases are endemic in many parts of the world. These diseases can cause widespread devastation of animal populations and crops. Given rapid movement of trade products nationally and internationally, even with strict biosecurity measures, disease outbreaks can still occur. Crops are grown year-round, processed throughout the state, imported from around the world, and sold nationally and internationally. With many manufacturers distributing their products on a national and sometimes international scale, food and feed safety continues to be an important component to Washington agriculture. In many cases, diseases may take several days to weeks to manifest resulting in a wider spread outbreak. These animal, crop, plan diseases and infestation outbreaks primarily pose a danger to our economy since they could result in immediate national and international embargos of Washington state agricultural products.

Previous occurrences – Animal and crop disease outbreaks occur frequently each year. The severity of each outbreak varies depending on virulence. In 2016, the Washington State Department of Agriculture (WSDA) sprayed an organic pesticide on 10,500 acres to prevent further spread of the Asian Gypsy Moth from infecting our state and national forests. In 2015 and 2016, WSDA euthanized hundreds of backyard poultry to prevent the spread of highly pathogenic avian influenza that was introduced via wild birds. The 2003 BSE outbreak in Eastern Washington caused immediate international embargos (some which are still in place today) from over 109 countries and an estimated loss to the U.S. beef industry of over $3.5 billion.

Probability of future events – Animal and crop disease outbreaks, pest infestations and food safety outbreaks occur regularly every year in Washington state. Many go unnoticed in the news, but on occasion result in serious illnesses or even death. Because Washington is a national and international leader in many agricultural areas the risk is high for future events.

Jurisdictions at greatest risk – All 39 counties in the state are at risk with special attention to Eastern Washington counties.

Special note – This profile will not attempt to estimate potential losses to industry facilities due to animal or crop disease outbreaks. However, this hazard profile will identify a number of industries that have a potential for closures due to disease outbreaks.

Risk Profile

The state's $51 billion food and agriculture industry employs approximately 164,000 people and contributes 12 percent to the state's economy. Rich soils, diverse climates and large-scale irrigation systems make Washington one of the most productive growing regions in the world. Washington's 35,900 farms power a diverse agricultural economy, with over 300 commodities grown in the state. Animals are raised, traded, sold and slaughtered year-round. Sale barns for livestock hold sales on a regular basis which can move animals throughout the western United States and British Columbia in any 24-hour period.

The state's deep-water ports and its proximity to important Asian markets also provide natural advantages for agricultural trade. In fact, Washington's top trading partners are Canada ($1.3 billion), Japan ($1.2 billion), China ($611 million), Philippines ($564 million) and South Korea ($432 million) with Washington's exports including products such as apples, seafood, vegetables, wheat, hay, french-fries and dairy (See Figure 1). An estimated $6.8 billion in food and agricultural products were exported through Washington state ports, the third largest total in the country. Our inland ports, barge systems and rail systems ship over 35 million tons of grain annually to Washington state ports for export.

Hazard Location, Extent, and Magnitude

Every county in the state is potentially vulnerable with central and eastern counties slightly higher due to the higher numbers of large farmlands and larger feedlots. While there are human health implications from infected food supply, it is likely the economic consequences of an agricultural infestation that will be most significant.

An outbreak of disease that can be transmitted from animal to animal or plant to plant represents an animal/crop/plant disease. Some disease outbreaks can have significant public health impacts and have potential to be zoonotic. Additionally, the animal/crop/plant infestation will likely have severe economic implications, cause significant crop productions losses or cause significant environmental damage.

Disease transmission may be transmitted through everyday human activity. As such, stringent biosecurity measures are heavily encouraged to prevent the spread of these diseases. The main vector for the spread of Avian Influenza in the U.S. (2015), Foot and Mouth Disease in the United Kingdom (2001) and South Korea (2011), or gypsy moths in the Pacific Northwest (ongoing) was though everyday activities, such as routine deliveries, imports of products from overseas and movement of workers from farm to farm.

Foreign and Trans-Boundary Animal Diseases – Those that are of significant economic, trade and/or food security importance for a considerable number of countries; which can easily spread to other countries and reach epidemic proportions; and where control/management, including exclusion, requires cooperation between several countries.

Below is a list of the 17 most damaging animal diseases, as determined by the U.S. Department of Agriculture (USDA) and The World Organization of Animal Health (OIE).

USDA National Damaging Animal Diseases

Disease	Animal Industries Affected	Public Health Threat?
Highly pathogenic avian influenza	Poultry	Yes, may be lethal
FMD	Cattle, swine, sheep, and other cloven-hoofed livestock	No
Rift Valley fever	Cattle, sheep	Yes, may be lethal
Exotic Newcastle disease	Poultry	Yes, minor effects
Nipah and Hendra viruses	Swine (Nipah), horses (Hendra)	Yes, may be lethal
Classical swine fever	Swine	No
African swine fever	Swine	No
Bovine spongiform encephalopathy agent	Cattle	Suspected
Rinderpest	Cattle, sheep	No
Japanese encephalitis	Swine, equine	Yes, may be lethal
African horse sickness	Equine	No
Venezuelan equine encephalitis	Equine	Yes, may be lethal
Contagious bovine pleuropneumonia	Cattle	No
Ehrlichia ruminantium (Heartwater)	Cattle, sheep, goats	No
Eastern equine encephalitis	Equine	Yes, may be lethal
Coxiella burnetii	Cattle, sheep, goats	Yes, may be lethal
Akabane	Cattle, sheep, goats	No

The introduction of some high consequence diseases may severely limit or eliminate Washington’s ability to move, slaughter and export animals or animal products. One of the key concerns regarding this hazard is the potential introduction of a rapid and economically devastating foreign animal disease, such as foot and mouth disease or bovine spongiform encephalopathy (BSE) disease. Washington state is a large cattle state with over one million head produced locally as well as imported. The loss of milk production or beef production would cause economic losses, unemployment, etc. to farmers, ranchers, butchers and other support professions. In 2003, the first confirmed domestic case of BSE disease was reported in Washington state and required quarantining and/or destruction of several herds. Response and recovery to infectious animal disease outbreaks will be lengthy, and many producers may not be able to return to business. There will be many indirect effects on our economy. Rumors of an infectious animal disease outbreak could cause significant damage to the markets, as was evidenced in the 2003 BSE “mad cow” disease outbreak in our state. Markets plummeted and over 109 countries banned import of U.S. beef into their countries, which resulted in over $3.5 billion in losses to the U.S. beef industry.

Crop/Plant Diseases – Disease is a natural part of every crop production system. This is true for every crop species and for each type of production system. Consequently, in any given year, the question is not whether or not disease will occur, but rather which diseases will occur and at what incidence and severity.

Crop/plant pest infestations can cause widespread crop/plant loss and severe economic hardship on our state farmers, landowners and businesses. Once an infestation occurs, the pest may become endemic, causing repeated losses in subsequent growing years. Loss of production will affect all related industries such as fuel, food, synthetics and processors in Washington state, and has the potential to have global impact as well.

Wheat is susceptible to leaf rust, wheat streak mosaic, barley yellow dwarf virus, strawbreaker and tan spot. Sorghum losses can occur when a crop is infected with sooty stripe early in the growing season. Gray leaf spot is a growing problem for corn crops.

Pests - Any crop can be threatened by pests. Pests can include wildlife, such as birds, rodents and humans, or insects such as moths, beetles, caterpillars and grasshoppers.

The European gypsy moth is an invasive species that has wreaked havoc on deciduous forests in North America. Introduced to the U.S. in 1869, the moths are now established in 19 East Coast and Midwest states. Washington state has conducted 85 eradication treatments since 1979 to prevent the species from gaining a permanent foothold. The WSDA completed treatments of seven sites totaling 10,500 acres in April and May of 2016. Infestation is not only a risk to crops in the field, but insect infestation can also cause major losses to stored grain. It is estimated that damage to stored grain by the lesser grain borer, rice weevil, red flour beetle and rusty grain beetle costs the U.S. about $500 million annually. The largest infestation ever recorded in North America is the mountain pine beetle in lodge pole pine forests. About 42 percent of federally threatened and endangered species are at risk primarily because of invasive species.

Food and Feed Safety - From manufactured food and dairy to commercial livestock feed and specialty pet food, Washington state supports a thriving food and feed processing industry. With many manufacturers distributing their products on a national and sometimes international scale, food and feed safety continues to be an important component to Washington agriculture. Routine surveillance of food and feed products is conducted on an ongoing basis to look for and control possible public health hazards such as pathogens responsible for foodborne and feed-borne illness, undeclared allergens and product mislabeling. With current Centers for Disease Control and Prevention (CDC) statistics estimating that 48 million Americans get sick and 3,000 die from foodborne disease every year, taking steps to ensure a safe food and feed production system in the state is an important contributor to the overall public health of Washingtonians. Contamination of food and food products could cause serious damage to Washington's $20.1 billion food processing industry. The loss in this industry would have a national ripple effect, impacting many other states.

Probability of Future Events

Determining the probability of future animal and crop disease outbreaks is difficult. There are many factors which influence the probability of future outbreaks. The state's potential risk is elevated by several factors: the large number of products arriving on a daily basis at any of our air or sea ports; infected animals coming into our region through sales and shipping containers that may not be known to be on board the vessels; animals being imported for sale (both as pets and as a food source); or the sale of imported agricultural products from other countries. Avian diseases could be brought in by migratory birds on their annual migration from Alaska and Canada, or from areas as far south as Mexico or South America. Even travelers to foreign countries who visit agricultural areas may unknowingly transport animal or crop diseases to this country. However, many factors can influence occurrences of animal and crop disease outbreaks:

Weather:

- Extreme weather can affect the existence and spread of animal and crop diseases. Winds can spread foot and mouth (FMD) disease up to 35 miles, given the right conditions.
- High and low temperatures can set the right conditions for an animal or crop disease to manifest once introduced into the environment.
- Extreme amounts of rain, snow, frost and drought can make animals and crops vulnerable to disease by weakening their ability to fight off disease.

Accidental Release:

- Farmers, industry, producers or sellers could accidentally introduce a disease onto a farm, livestock sale yard, processing facility, etc. without knowing it. In the 2003 BSE outbreak, an affected cow entered Washington state as part of a herd from a sale that originated in Canada.
- Infected crops or animals from other countries that are not caught via bio-security screenings or routine inspections during entry into the U.S.

Intentional Release:

An intentional release of an animal or crop disease into the U.S. could easily be carried out via a criminal or terrorist act.

Potential Impacts of Climate Change

With the advent of climate change coming into worldwide focus, it is necessary to take into account the potential effects this emerging climate crisis may have on the dangers associated with animal, crop, and plant diseases and infestation outbreaks. According to a 2005 Governor’s report prepared by the Climate Impacts Group titled *Uncertain Future: Climate Change and its Effects on Puget Sound*, “[From] palaeoclimatological evidence, we know that over the history of the earth high levels of greenhouse gas concentrations have correlated with, and to a large extent caused, significant warming to occur, with impacts generated on a global scale.” While the report also indicates that the “…ultimate impact of climate change on any individual species or ecosystem cannot be predicted with precision,” there is no doubt that Washington's climate has demonstrated change.

In July 2007, the Climate Impacts Group launched an unprecedented assessment of climate change impacts on Washington state. *The Washington Climate Change Impacts Assessment* (WACCIA) involved developing updated climate change scenarios for Washington state and using these scenarios to assess the impacts of climate change on the following sectors: agriculture, coasts, energy, forests, human health, hydrology and water resources, salmon and urban stormwater infrastructure. The assessment was funded by the Washington state Legislature through House Bill 1303.

In 2009, the Washington state Legislature approved the *State Agency Climate Leadership Act* Senate Bill 5560. The Act committed state agencies to lead by example in reducing their greenhouse gas (GHG) emissions to: 15 percent below 2005 levels by 2020; 36 percent below 2005 by 2035; and 57.5 percent below 2005 levels (or 70 percent below the expected state government emissions that year, whichever amount is greater). The Act, codified in RCW 70.235.050-070, directed agencies to annually measure their greenhouse gas emissions, estimate future emissions, track actions taken to reduce emissions and develop a strategy to meet the reduction targets. Starting in 2012 and every two years thereafter, each state agency is required to report to Washington State Department of Ecology the actions taken to meet the emission reduction targets under the strategy for the preceding biennium.

Recognizing Washington’s vulnerability to climate impacts, the Legislature and Gov. Chris Gregoire directed state agencies to develop an integrated climate change response strategy to help state, tribal, and local governments, public and private organizations, businesses and individuals prepare. The state Departments of Agriculture, Commerce, Ecology, Fish and Wildlife, Health, Natural Resources and Transportation worked with a broad range of interested parties to develop recommendations that form the basis for a report by the Department of Ecology: *Preparing for a Changing Climate: Washington State’s Integrated Climate Change Response Strategy*.

Over the next 50 to 100 years, the potential exists for significant climate change impacts on Washington's coastal communities, forests, fisheries, agriculture, human health and natural disasters. These impacts could potentially include increased annual temperatures, rising sea level, increased sea surface temperatures, more intense storms and changes in precipitation patterns. Therefore, climate change has the potential to impact the occurrence and intensity of natural disasters, potentially leading to additional loss of life and significant economic losses. Recognizing the global, regional and local implications of climate change, Washington state has shown great leadership in addressing mitigation through the reduction of greenhouse gases.

The forces that shape the climate are also critical to farm productivity. Human activity has already changed atmospheric characteristics such as temperature, rainfall, levels of carbon dioxide (CO_2) and ground level ozone. Warmer climate may give positive effects on food production like the possibility of longer growing seasons; however, the increased potential for weather extremes will pose challenges for farmers. Increased frequency of heat stress, drought and flood negatively affect crop yields and livestock. Moreover, water supply and soil moisture could make it less feasible to continue crop production in certain areas. The potential loss of snowpack in the Cascades will diminish water needed for summer irrigation for crops in the Columbia Basin and impact salmon recovery across the Northwest. Finally, climate variability and change will modify the risks of fires, weeds, pests and pathogen outbreaks.

Yakima Valley

In 2004, research at the Pacific Northwest National Laboratory (PNNL) determined that the $1.3 billion output in the Yakima River Basin was due to water availability. Past droughts caused 10 to 15 percent losses of economic output, not including the accumulation of water loss over the years. Compared to a “good year” where the outputs are estimated at $901 million, droughts and crop losses will become more prevalent due to water shortages increasing from $13 to $79 million per year by mid-century. Water shortages will cause higher costs for farmers and amplify economic losses during drought years. Expected global increases in temperatures will have economic effects not easy to quantify. Decreased snowpack and earlier runoff will decrease streamflow. Higher temperatures will increase evaporation in the soil and decrease its capacity to hold moisture for plants during the hottest parts of the growing season. Insects will find a haven in warmer temperatures and become a greater problem. Increased numbers of hot days (over 100 degrees Fahrenheit) are expected to cause increased levels of heat related illness, which makes the agricultural workers population especially vulnerable.

Studies that focus on the water availability to the 370,000 acres (1,500 km^2) of orchards, vineyards and food crops within the Yakima River Valley are dependent on irrigation which draws water from only five reservoirs. These in turn are dependent on snowpack from the Cascade Mountains. With the arrival of early snowfall, warmer temperatures and a premature runoff, irrigation water supply is predicted to drop 20 to 40 percent by mid-century. The loss to agriculture in the Yakima River Valley would be $92 million for a 2 degrees Celsius increase and $163 million for a 4 degrees Celsius increase.

Dairy production

A significant rise in global temperatures will negatively affect dairy production in Washington state which had a total of 560 dairy farms at the end of 2004. Each region will be affected differently based on the different climate and temperature fluctuations. Current predictions forecast that by 2075, milk production in the Yakima River Valley will drastically decrease during the summer months. The worst effects of climate change will be a decrease in daily milk production from 27 kilograms to 20 kilograms in the month of August. Whatcom County dairy farms are predicted to be less affected by climate change than Yakima River Valley. Summer milk production in Whatcom County is projected to fall from a little under 27 kilograms per cow, per day to slightly more than 25 kilograms per cow, per day. In both regions the lower milk production is directly correlated to the decrease in consumption of food stuffs. The decrease in food availability during summer is due to increasing annual temperatures that shift precipitation levels and cause a faster run-off of snowpack. With less food for the cows, milk production drastically decreases during the summer months. Higher temperatures cause a decrease in milk production.

Wine

Washington state currently holds second place, following California, for U.S. wine production. A change in climate will cause vineyards to move. In 2004, wine grapes accounted for $127.5 million and were the state's fourth largest fruit group in terms of value. In 2005, the wine industry as a whole was a $3 billion industry, providing the equivalent of 14,000 full-time jobs.

The Yakima and mid-Columbia valleys are the most heavily populated vineyard regions. The predicted water shortage within the next decades could lead to a potential crop loss from $13 million to $79 million by mid-century. Because wine varieties are highly sensitive to temperatures, an increase could cause several Eastern Washington areas to move out of the ideal range for certain varietals. The climate shift could make western areas such as Puget Sound more ideal for wine production. If the magnitude of the warming is two degrees Celsius or larger, then a region may potentially shift into another climate maturity type, which is the specific climate favorable to maturing a certain type of grape. For instance, the chardonnay grapes of Western Washington mature well at 14 to 16 degrees Celsius, while merlots typically produced in Eastern Washington do best at 16 to 19 degrees Celsius. The shift of vineyard concentration to the coastal regions would mean a shift in local land value and use, production, revenue and employment.

Wheat

Eastern Washington produces a large amount of wheat that is affected by climate. In a recent study, winter wheat productions were taken at different elevations, both with and without irrigation, and the best yields were in areas with a lot of rainfall, temperate conditions and at elevations from 1,000 to 1,500 meters. Both non-irrigated and irrigated harvests have increased with global warming, which has also allowed for increased production at higher elevations. The harvests also improved with the presence of higher levels of carbon dioxide.

Cranberries

Washington is the fifth largest supplier of cranberries in the U.S., producing three percent of total U.S. production. There are three growing regions in Washington: Whatcom County, Grays Harbor County and Pacific County. These berries could be affected by higher winter temperatures and rising sea levels due to climate change.

References

Washington State Department of Agriculture: https://agr.wa.gov/

WSDA Plant Protection: https://agr.wa.gov/Portals/PI/

WSDA Animal Services: https://agr.wa.gov/Portals/An/

WSDA Commodity Inspection:

https://agr.wa.gov/AboutWSDA/Divisions/CommodityInspection.aspx

United States Department of Agriculture Site

USDA National Agricultural Statistics Service: https://www.nass.usda.gov/

USDA Animal Plant Health Inspection Service: https://www.aphis.usda.gov/aphis/home/

USDA Plant Protection and Quarantine: https://www.aphis.usda.gov/aphis/ourfocus/planthealth

USDA Food Safety and Inspection Service: https://www.fsis.usda.gov/wps/portal/fsis/home

Food and Drug Administration: https://www.fda.gov/

Avalanche Risk Summary

Washington State Risk Index for Avalanche (WaSRI-A)	MEDIUM-LOW
LIKELIHOOD	HIGH
The state experiences a number of avalanche events annually. Most of these are small events in restricted regions. Annual likelihood of a major event is 42%, and of multiple events 35%.	
HAZARD AREA	MEDIUM
30% of the state is exposed to avalanche hazards.	
POPULATION	LOW
Less than 3% of the state population is exposed to avalanche hazards.	
VULNERABLE POPULATION	LOW
Less than 1% of the state population resides in areas ranked medium or higher on social vulnerability and also exposed to avalanche hazards.	
BUILT ENVIRONMENT	LOW
Less than 5% of the general building stock of the state is located in areas exposed to avalanche hazards.	
CRITICAL INFRASTRUCTURE	LOW
10% of the facilities are located in areas exposed to avalanche hazards. Road segments crossing the Cascades are vulnerable to avalanches, particularly Stevens Pass (Route 2) and Snoqualmie Pass (I-90).	
STATE FACILITIES	LOW
Less than 5% of state-owned facilities are located in areas exposed to avalanche hazards. Less than 1% of the state-leased facilities are located in areas exposed to avalanche hazards.	
FIRST RESPONDERS	LOW
10% of the fire stations are located in areas exposed to avalanche hazards. 14% of the law enforcement facilities are located in areas exposed to avalanche hazards. 10% of the EMS facilities are located in areas exposed to avalanche hazards.	
ECONOMIC CONSEQUENCES	MEDIUM
Counties ranked high on WaSRI-A account for less than 5% of real state GDP. However, the functionality of vulnerable transportation corridors may be interrupted for short periods.	
ENVIRONMENTAL IMPACTS	MEDIUM
31% of critical environmental areas are exposed to avalanche areas.	

Avalanche Risk Profile

Hazard Description

An Avalanche is a mass of snow in swift motion travelling downhill. Technically, an avalanche is any amount of snow sliding down a mountainside. It can be compared to a landslide only with snow instead of earth. The flow can be composed of ice, water, soil, rock and trees. The amount of damage depends on the type of avalanche, the composition and consistency of the material contained in the avalanche, the velocity and force of the flow and the avalanche path. As an avalanche approaches the bottom of the slope, it gains speed and power; this can cause even the smallest of snow slides to be a major disaster.

The slope failure associated with an avalanche is caused by several factors; however, large accumulations of snow on a steep slope is the most common cause. Avalanches can occur on slopes averaging between 25 to 50 degrees; the majority of avalanches occur on slopes between 30 and 40 degrees. They are triggered by natural seismic or climatic factors such as earthquakes, thermal changes, blizzards or by human activities. Disastrous avalanches occur when massive slabs of snow break loose from a mountainside and shatter like broken glass as they race downhill. These moving masses can reach speeds of 80 mph (130 kph) within roughly five seconds. Victims caught in these events seldom escape.

Avalanches are most common during and in the 24 hours right after a storm that releases 12 inches (30 centimeters) or more of fresh snow. The quick pileup overloads the underlying snowpack, which causes a weak layer beneath the slab to fracture. The layers are an archive of winter weather: big dumps, drought, rain, a hard freeze and more snow. How the layers bond often determines how easily one will weaken and cause a slide.

There are two types of avalanches, loose and slab, and two types of slab avalanches, soft and hard. Avalanches can be either dry or wet. Although the most dangerous avalanche is the slab avalanche, loose slides can and do produce injury and death. Loose avalanches occur when grains of snow cannot hold on to a slope and begin sliding downhill, picking up more snow and fanning out in an inverted “V” shape. Slab avalanches occur when a cohesive mass of snow breaks away from the slope all at once. Most slides in the Northwest are slab avalanches.

An avalanche path is determined by the physical limitations of the boundaries of the local terrain and man-made features. An avalanche may follow a path along a channelized or confined terrain, similar to debris flows or streams, before spreading onto alluvial fans or gentle slopes. The avalanche path itself varies in width as it transitions along the path, depending on the confinement of the terrain and the velocity of flow. An avalanche path is described as having three specific transition zones:

- The **Starting Zone** is typically located near the top of the ridge, bowl or canyon, with steep slopes of 25 to 50 degrees;

- The **Track Zone** is the reach with mild slopes of 15 to 30 degrees and the area where the avalanche will achieve maximum velocity and considerable mass; and
- The **Runout Zone** is the area of gentler slopes (5 to 15 degrees) located at the base of the path, where the avalanche decelerates, and massive snow and debris deposition occurs.

When avalanche material is deposited in the Runout Zone, it tends to harden quickly. Even very light avalanches of powdery, dry snow can form ice-like masses after being “worked” by the mechanical forces involved in the slide. Victims are rarely able to extract themselves from even very shallow burials.

Avalanches occur for one of two basic reasons:

1. Either the load on a slope increases faster than snow strength; or
2. Snow strength decreases.

Slab avalanches occur when the stresses on a slab overcome the slab’s attachment strength to the snow layer below. A decrease in strength is produced through warming, melting snow or rain. Decreased strength within the existing snowpack may also result from strong temperature gradients and associated vapor transfer that produces recrystallization within the existing snow matrix. An increase in stress may be produced by the weight of additional snowfall, or a skier or snowmobile. Dry slab avalanches can travel 60 to 80 mph or more, reaching these speeds within five seconds after the fracture; they account for most avalanche fatalities. Wet slab avalanches occur when warming temperatures or rain increase the creep rate of the surface snow, putting additional forces on the slab’s attachment to the layer below. When water percolating through the top slab weakens the layer, and dissolves its bond with a lower layer, it decreases the ability of the weaker, lower layer to hold on to the top slab, as well as decreases the slab’s strength. In 90 percent of avalanche fatalities, the weight of the victim or someone in the victim’s party triggers the slide. An avalanche is like a dinner plate sliding off a table; a slab of snow shatters like a pane of glass with the victim in the middle.

A number of weather, terrain and snowpack factors determine avalanche danger:

Weather:

- Storms – A large percentage of all snow avalanches occur during and shortly after storms.
- Rate of snowfall – Snow falling at a rate of one inch or more per hour rapidly increases avalanche danger.
- Temperature – Storms starting with low temperatures and dry snow, followed by rising temperatures and wetter snow, are more likely to cause avalanches than storms that start warm and then cool with snowfall.
- Wet snow – Rainstorms or spring weather with warm, moist winds and cloudy nights can warm the snow cover resulting in wet snow avalanches. Wet snow avalanches are more likely on sun-exposed terrain (south-facing slopes) and under exposed rocks or cliffs.

- Wind is the most common cause of avalanches. Wind can deposit snow 10 times faster than snow falling from storms. Wind erodes snow from the upwind side of obstacles and deposits snow on the downwind (lee) side. This is called "wind loading".

Terrain:

- Ground cover – Large rocks, trees and heavy shrubs help anchor snow but also create stress concentrations between anchored and unanchored snow.
- Slope profile – Dangerous slab avalanches are more likely to occur on convex slopes that produce stress concentrations within surface snow due to varying creep rates.
- Slope aspect – Leeward slopes are dangerous because windblown snow adds depth and creates dense slabs. South facing slopes are more dangerous in the springtime due to increasing solar effects.
- Slope steepness – Snow avalanches are most common on slopes of 30 to 45 degrees.

Snowpack:

- Snow texture - The feel, appearance or consistency of the snow determined by the shape, size and attachment of snow grains that comprise the particular snow layer. Also, the inter-granular relationship — the overall feel of a snow layer, specifically the relative quantities of the different types and sizes of snow particles in a particular layer, and the size, shape and arrangement of grains as seen with a hand lens. A layer of small grained moist snow has a distinctly different texture — much more cohesive and able to make snowballs — than well-faceted snow that falls apart in one's hands and exhibits very little internal cohesion.
- Snow layering – The snowpack is composed of ground-parallel layers that accumulate over the winter. Each layer contains ice grains that are representative of the distinct meteorological conditions during which the snow formed and was deposited. Once deposited, a snow layer continues to evolve under the influence of the meteorological conditions that prevail after deposition.
- Snow bonding - In the absence of strong temperature gradients within a dry snowpack, this is the normally stabilizing or "rounding" process whereby individual snow grains or layers come into contact and gradually strengthen the ice skeleton or snow layer(s) through sintering or the formation of ice "necks" between the grains. This sintering process results from shape or size driven vapor pressure differences between or within grains or layers and involves preferential transfer of water vapor and subsequent vapor deposition. The associated redistribution of water vapor results in inter-granular attachments or bonds between grains through an expanding ice matrix, and typically results in gradual strengthening of the surrounding snowpack structure.

It must be noted that in the presence of strong temperature gradients within or between snow layers, a different metamorphic process in the snow cover can occur which is known as faceting — a process that results in new crystal growth and/or recrystallization of existing snow grains, often producing general weakening of the snow structure. Faceting is characterized by strong (often local) temperature gradients in the snow pack and resulting strong vapor pressure gradients that move mass from warmer grains (higher vapor pressure) to colder grains (lower vapor pressure). As the process evolves and more mass is transferred, faceting snow loses existing grain bonds, forms new grains, and in general becomes more disaggregated and sugary (hence the related term “sugar snow”). In observations and tests, the hardness of a faceting snow layer decreases with time and it becomes easier to penetrate and pull individual faceted grains out of a snow pit wall.

Avalanche Location, Extent, and Magnitude

In Washington state, avalanches occur in four mountain ranges: the Cascade Range, which divides the state East and West; the Olympic Mountains in northwest Washington; the Blue Mountains in southeast Washington; and the Selkirk Mountains in northeast Washington. The avalanche season begins in November and continues until early summer for all mountain areas of the state. In the high alpine areas of the Cascades and Olympics, the avalanche season continues year-round.

Since 1995, a total of 106 significant avalanche events have occurred in the state, with King, Lewis, Pierce and Whatcom counties experiencing the highest number of these events. There were 63 avalanche related fatalities reported from 1995 to 2017. These were among the highest number of avalanche related fatalities in the nation.

Avalanches tend to be common in mountains that accumulate standing snowpack. Generally, avalanches occur due to a combination of snow load and loss of cohesion between layers of snow. Storms, wind, rain, changes in temperatures, human activity and seismic events can all trigger avalanches. Contrary to popular belief, loud noises do not cause avalanches. Avalanches most commonly occur on slopes of between 30 to 45 degrees.

Several classification systems are used throughout the world in rating hazards and conditions associated with avalanches. In the United States, a five-level scale is used to classify the size of an avalanche, as shown in the table below (Source: Avalanche.org).

Avalanche Classifications	
Size	Destructive Potential
1	Sluff or snow that slides less than 50m (150 feet) of slope distance
2	Small, relative to path
3	Medium, relative to path
4	Large, relative to path
5	Major or maximum, relative to path

Avalanche forecasting has been the focus of numerous papers that describe the objective of avalanche forecasting (McClung 2002a), the nature of the reasoning process (LaCha- pelle 1966, 1980; McClung 2002a), the types of observations used for forecasting (Perla and Martinelli 1975;

LaChapelle 1980; McClung 2002b) and the human influences on the hazard assessment process (McClung 2002a).

Avalanche forecast centers in the United States use the danger categories as described in the table. The scale was designed to facilitate communication between forecasters and the public. The categories represent the probability of avalanche activity and recommend travel precautions. As of 2010, the United States and Canada adopted and use this avalanche danger scale.

WHAT Danger Level (Color)	WHY Avalanche Probability / Triggers	WHERE Degree and Distribution of Avalanche Danger	WHAT TO DO Recommended Action in the Backcountry
LOW (GREEN)	Natural avalanches very unlikely. Human-triggered avalanches unlikely.	Generally stable snow. Isolated areas of instability.	Travel is generally safe. Normal caution is advised.
MODERATE (YELLOW)	Natural avalanches unlikely. Human-triggered avalanches possible.	Unstable slabs possible on steep terrain.	Use caution in steeper terrain on certain aspects (defined in accompanying statement).
CONSIDERABLE (ORANGE)	Natural avalanches possible. Human-triggered avalanches probable.	Unstable slabs probable on steep terrain.	Be increasingly cautious in steeper terrain.
HIGH (RED)	Natural and human-triggered avalanches likely.	Widespread natural or human-triggered avalanches certain.	Unstable slabs likely on a variety of aspects and slope angles.
EXTREME (BLACK)	Travel in avalanche terrain is not recommended. Safest travel on windward ridges of lower angle slopes without steeper terrain above.	Extremely unstable slabs certain on most aspects and slope angles. Large, destructive avalanches possible.	Travel in avalanche terrain should be avoided and travel confined to low-angle terrain well away from avalanche path run-outs.

Property damage associated with avalanches is a function of several factors. Large external lateral loads can cause significant damage to structures and fatalities. The below table indicates the estimated potential damage for a given range of impact pressures (Source: Avalanche.org).

Avalanche Impact Pressures Related to Damage		
kPa	lbs/ft2	
2-4	40-80	Break windows
3-6	60-100	Push in doors, damage walls, roofs
10	200	Severely damage wood frame structures
20-30	400-600	Destroy wood-frame structures, break trees
50-100	1000-2000	Destroy mature forests
>300	>6000	Move large boulders

Past Occurrences and Future Probability of Occurrence

Between 1960 and 2017, the state of Washington experienced 129 avalanche events resulting in property losses worth $2.7 million (table A4). These events also resulted in 50 injuries and 46 fatalities. Most hazard events were experienced in King county (27) followed by Pierce (22), Lewis (20) and Whatcom (11) counties.

Avalanche Events (1960 2017)				
County	Number of Events	Total Property Damage ($2016)	Total injuries	Total Fatalities
Adams	1	5,976.65	0	1
Asotin	0	-	0	0
Benton	1	5,976.65	0	0
Chelan	6	630,237.69	12	3
Clallam	0	-	0	0
Clark	1	5,976.65	0	0
Columbia	0	-	0	0
Cowlitz	0	-	0	0
Douglas	1	5,976.65	0	0
Ferry	0	-	0	0
Franklin	1	5,976.65	0	0

Avalanche Events (1960 2017)				
County	Number of Events	Total Property Damage ($2016)	Total injuries	Total Fatalities
Garfield	0	-	0	0
Grant	2	241,889.47	0	0
Grays Harbor	0	-	0	0
Island	0	-	0	0
Jefferson	0	-	0	0
King	27	6,078.72	12	10
Kitsap	0	-	0	0
Kittitas	5	575,512.96	0	4
Klickitat	1	5,976.65	0	0
Lewis	20	5,976.65	7	5
Lincoln	1	-	0	0
Mason	0	-	0	0
Okanogan	4	630,237.69	1	2
Pacific	0	-	0	0
Pend Oreille	1	-	0	0
Pierce	22	5,976.65	15	7
San Juan	0	-	0	0
Skagit	9	6,139.90	2	2
Skamania	1	5,976.65	0	0
Snohomish	9	5,976.65	1	6
Spokane	1	-	0	0
Stevens	1	-	0	0
Thurston	0	-	0	0
Wahkiakum	0	-	0	0
Walla Walla	1	5,976.65	0	0
Whatcom	11	5,976.65	2	7

Avalanche Events (1960 2017)				
County	Number of Events	Total Property Damage ($2016)	Total injuries	Total Fatalities
Whitman	0	-	0	0
Yakima	2	575,512.96	0	0
Grand Total	129	2,737,329.19	50	46

Source: Hazards & Vulnerability Research Institute (2017). The Spatial Hazard Events and Losses Database for the United States, Version 16.0 [Online Database]. Columbia, SC: University of South Carolina. Available from http://www.sheldus.org

The following table provides a list of recent significant avalanche events and their impact. This is only a list of selected events to provide a general assessment of common risks and impacts commonly associated with avalanche events in Washington.

Key Avalanche Events				
Date	Place	Fatalities	Activity	Summary
2017-04-11	Red Mountain, north of Snoqualmie Pass	1	SKI	1 backcountry tourer caught, killed.
2017-03-04	Hawkins Mountain, north of Cle Elum	1	SNOWMOBILE	2 snowmobilers caught, 1 partially buried, 1 buried and killed
2017-01-04	Near Crystal Mountain, south of Greenwater	1	SKI	1 backcountry tourer caught, partially buried, and killed
2016-12-27	West of White Pass Ski Area	1	SKI	1 sidecountry rider caught, killed
2016-01-24	Mt Baker, Mt. Herman, north flank	1	SKI	2 backcountry skiers caught, 1 injured, 1 killed
2015-12-31	Snoqualmie Pass, Granite Mountain	1	SNOWSHOE	1 snowshoer caught and killed
2015-12-19	Snoqualmie Pass, Commonwealth Basin	1	SKI	1 backcountry skier caught, buried and killed

Key Avalanche Events

Date	Place	Fatalities	Activity	Summary
2014-05-28	Mt. Rainier National Park, Mt. Rainier, Liberty Ridge	6	CLIMB	6 climbers caught, buried and killed
2014-05-14	North Cascades National Park, Mt Shuksan	1	SKI	1 backcountry skier caught and killed
2014-03-22	Snoqualmie Pass, Granite Mountain, south side	1	SKI	1 backcountry skier caught, buried and killed
2014-01-18	Cascade Mountains, Barlow Pass, Lewis Peak	1	CLIMB	1 climber caught and killed
2013-04-13	Red Mountain, Snoqualmie Pass, Cascade Mountains	1	SNOWSHOE	2 snowshoers caught, 2 buried, and 1 killed
2013-04-13	Granite Mountain, Snoqualmie Pass, Cascade Mountains	1	HIKE	3 hikers caught, 2 partly buried and injured, 1 buried and killed
2012-02-19	Alpental, WAC Bluffs, 80s Chute	1	SNOWBOARD	2 sidecountry snowboarders caught, 1 killed
2012-02-19	Stevens Pass, Cowboy Mountain, Tunnel Creek	3	SKI	5 sidecountry skiers caught, 1 partly buried, 3 buried and killed
2011-03-27	Steven's Pass	1	SNOWBOARD	1 snowboarder caught, carried, and killed
2011-03-05	Mount Cashmere, above Trout Creek, Leavenworth	1	SKI	1 Backcountry skier caught and killed
2011-02-01	Snoqualmie Pass	1	SKI	1 Backcountry skier killed after breaking cornice and falling
2010-12-04	Morning Star Peak, north central Washington Cascades	1	CLIMB	1 climber caught, partially buried, and killed

Key Avalanche Events				
Date	**Place**	**Fatalities**	**Activity**	**Summary**
2010-06-05	Ingraham Direct Route, Mount Rainier	1	CLIMB	11 climbers caught, 10 recovered, 1 still missing - presumed dead
2008-12-30	Rockford, WA (near Spokane, eastern WA)	1	OTHER	Roof Avalanche kills 85 year old women
2008-12-28	Brown Bear Basin near Harts Pass	1	SNOWMOBILE	1 snowmobiler caught, buried, and killed
2008-01-04	Above Mountain Loop Highway near Mount Pilchuck	1	HIKE	3 hikers caught, 2 partially buried, 1 completely buried and killed
2008-01-01	Excelsior Pass area, north of Mount Baker	2	SNOWMOBILE	5 snowmobilers caught, 2 killed, and 1 injured
2007-12-18	Mt Rainier National Park - Edith Creek Basin	1	SNOWSHOE	1 snowshoer caught, buried, and killed
2007-12-02	Near Source Lake, Snoqualmie Pass WA	2	HIKE	3 hikers caught, 2 completely buried, 1 mostly or completely buried, 2 killed
2007-12-02	Back country north of Crystal Mt Resort	3	SNOWBOARD	3 missing snowboarders presumed buried and killed
2007-02-24	Mt Rainier National Park (just west of Crystal Mountain Ski Area Boundary)	1	SKI	1 skier caught, buried and killed
2006-04-18	Mount Herman, west of Mt. Baker Ski Area	1	SKI	1 skier caught, carried, and killed
2006-03-19	Tiffany Mountain near Conconully	1	SNOWMOBILE	2 snowmobilers caught, 1 totally buried and killed, 1 partially buried
2005-01-12	Snoqualmie Pass, CLOSED Ski Area	1	SKI	2 skiers caught, 1 partially buried, 1 buried and killed

Key Avalanche Events

Date	Place	Fatalities	Activity	Summary
2004-10-24	Mt. Rainier, Ingraham Glacier Area	1	CLIMB	2 climbers caught and buried, one killed
2004-06-13	Liberty Ridge, Mt Rainier	2	CLIMB	2 climbers caught and killed
2004-04-26	near the Mt Baker ski area	1	SNOWBOARD	1 snowboarder caught and killed in small slide
2004-03-05	Near Salmon la Sac	1	SNOWMOBILE	One snowmobiler caught, buried, killed
2003-12-17	Navajo Peak WNW of Blewett Pass	1	SNOWMOBILE	1 snowmobiler caught, buried and killed
2003-12-13	Near the Alpental ski area, Snoqualmie Pass	1	SNOWSHOE	1 snowshoer caught, buried, still missing and presumed dead
2003-12-12	Near Artists Point near the Mt Baker ski area	1	SNOWSHOE	3 snowshoers caught and buried, 1 killed, 2 survived 24 +hour burial
2002-12-29	Norse Peak, near Crystal Mtn. Resort	1	SKI	7 skiers caught, 6 partially buried, 1 injured, 1 buried and killed.
2001-04-11	Easton Glacier, South side of Mount Baker	1	SNOWMOBILE	1 snomobiler caught, buried, and killed. Missing hiker recovered.
2001-02-17	Mountains North of Cle Elum, WA	1	SNOWMOBILE	1 snowmobiler caught, buried, and killed
2001-01-29	Twin Lakes, Chelan County	1	SNOWSHOE	2 snowshoers, 3 dogs caught, 1 person killed. 1 Dog killed.
2000-01-16	Crystal Mountain Ski Area	1	SKI	2 skiers in closed area, 1 caught buried and killed
1999-02-14	Near Mt. Baker	2	SNOWBOARD	1 snowboarder dead; 1 skier caught, buried-still missing and presumed dead

Key Avalanche Events				
Date	**Place**	**Fatalities**	**Activity**	**Summary**
1999-01-18	Near Mt. Baker	1	SNOWBOARD	Snowboarder caught, buried-still missing and presumed dead

The state experienced at least one significant avalanche in 24 of the last 57 years (1960-2017). It is notable that most incidents of avalanche tend to cluster in the same year with 20 of the 24 years experiencing two or more major events in the same year. Most avalanches in Washington state happened in 1975. Since then, the next three highest annual number of events were all experienced in this decade (2010 onwards). It is likely that we are experiencing early impacts of changing climatic conditions that will result in greater frequency and intensity of avalanches in the region as our warming atmosphere will contain more moisture. However, in the more distant future avalanches will become less frequent as temperatures continue to rise and there is less snow pack at lower elevations.

Currently based on the past records since 1960 the likelihood of a major avalanche in any given year is 42 percent. The likelihood of multiple (two or more) avalanches in any given year is 35 percent. Since 2001, the likelihood of a major avalanche in any given year has increase to 70 percent and that of multiple events is 50 percent.

Years with at least One Major Avalanche Events (1960 2017)	
Year	**Total Major Events**
1974	1
1975	19
1985	1
1994	2
1996	2
1997	5
1998	2
1999	2
2000	6
2001	2

Years with at least One Major Avalanche Events (1960 2017)	
Year	Total Major Events
2002	4
2003	4
2005	1
2006	5
2007	3
2008	4
2009	2
2010	12
2011	11
2012	9
2013	9
2014	18
2015	1
2016	4
Grand Total	129

Source: Hazards & Vulnerability Research Institute (2017). The Spatial Hazard Events and Losses Database for the United States, Version 16.0 [Online Database]. Columbia, SC: University of South Carolina. Available from http://www.sheldus.org

Relationship to Other Hazards

Avalanches generally do not influence or impact the initiation of other hazards. They generally occur independently of other hazards, although they are often caused by increased snow pack from winter precipitation. Earthquakes, thermal changes and blizzards, on the other hand, are likely to trigger avalanches. Avalanche impacts (damaged structures, loss of life, etc.) can be similar to those resulting from landslides, mud/debris flows and rockfalls. However, locations of past avalanche paths do have the ability to increase the immediate area's susceptibility to future landslides and flooding due to the removal and transport of trees, vegetation and other ground materials.

Avalanche Mitigation

The Washington State Department of Transportation (WSDOT) conducts active winter time avalanche control or mitigation on two of the state's mountain highway passes: Stevens Pass on U.S. Route 2 and Snoqualmie Pass on Interstate 90. This means avalanches are triggered intentionally on slopes above the roadways in a controlled environment to minimize traffic disruption and promote public safety. It also conducts passive avalanche control through elevated roadways so avalanches can pass under highways, over snow sheds over highways, into catchment basins to stop avalanche flow, and into diversion dams and berms to keep snow off highways. In addition to these controls, WSDOT closes three passes in winter because avalanches are so prevalent that control measures would be too costly and hazardous. These passes are Chinook Pass (elevation 5,430 feet) that connects Enumclaw and Yakima, Cayuse Pass (elevation 4,675 feet) that connects Chinook and White Pass along the east slope of the Cascades, and Rainy/Washington Passes (elevations 4,855 feet and 5,500 feet) along the North Cascades Highway, which connects the Skagit Valley to Eastern Washington. This portion of the North Cascades Highway holds the distinction of being among the top areas in the United States for most avalanche chutes per mile of highway. Some areas of this highway have five avalanche paths in a mile of roadway. Specific times of the winter when these passes close vary from year to year and are based on snow accumulation, personnel, avalanche risk and a variety of other factors. Opening for the passes varies as well, although the target date for their opening is May 1 to coincide with the beginning of fishing season.

Avalanche control is a winter-long task on the two primary travel corridors in Washington that must remain open all year long. The more heavily impacted corridors are Interstate 90 -Snoqualmie Pass (elevation 3,022 feet); the primary East-West corridor serving the Seattle-Tacoma-Olympia area and U.S. Highway 2 - Stevens Pass (elevation 4,061 feet) connecting Everett and Wenatchee. Snoqualmie Pass is the only interstate highway link in Washington through the Cascades. It averages 450 inches of snowfall each winter and has traffic volumes of over 32,000 vehicles a day, including 8,000 trucks. Interstate 90 is closed an average of 80 hours per year due to avalanches. It is estimated that a two-hour closure of Snoqualmie pass costs the state's economy over $1 million.

Intermittent winter time avalanche control is also used by WSDOT along U.S. 12 (White Pass) when conditions warrant, however, an avalanche control program for U.S. 12 does not exist at this time. Occasional closures due to avalanche danger have occurred. Avalanche control is also done during spring time re-opening of State Route 410 (Chinook and Cayuse Passes) and State Route 20 (Washington Pass).

Transportation Corridor Avalanche Control

Snow slides are a fact of life in the Cascade Mountains. WSDOT avalanche control technicians work to reduce the potential hazard using all available experience and tools. This means operating a comprehensive program to control when and how to bring down unstable snow.

Each winter, WSDOT stations specially trained avalanche control teams at Hyak, near the Interstate 90 Snoqualmie Pass summit and at Berne Camp, near the U.S. 2 Stevens Pass summit. The teams work to reduce the avalanche hazard as well as the number and duration of highway closures.

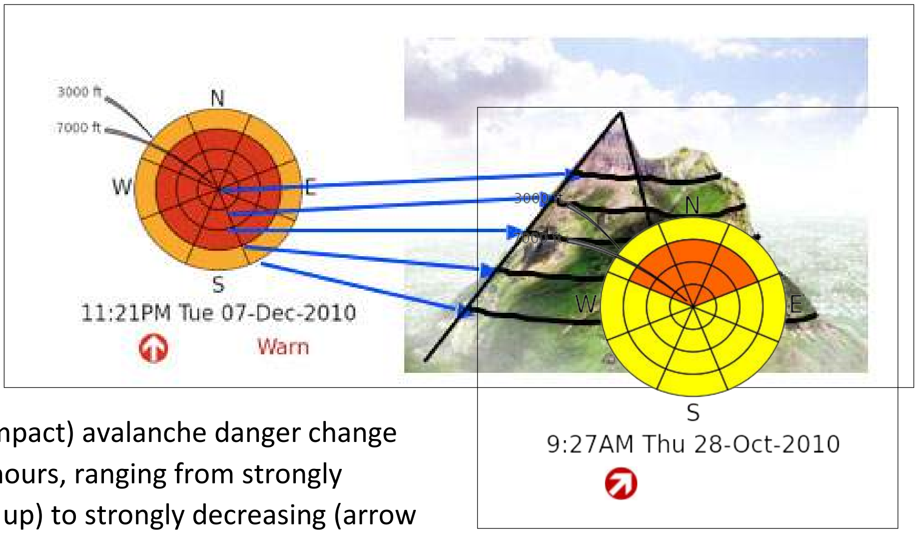
Active avalanche control is when crews intentionally trigger an avalanche. To do this, WSDOT stops traffic and triggers the avalanche. Avalanche control must be done during heavy snowfall. However, to be most effective, active control work is done just as the snow is becoming unstable, but before it slides. Whenever possible, the control work is scheduled outside of peak traffic hours.

When an avalanche hazard develops, WSDOT uses artillery or explosives to trigger the avalanche. These are various methods of delivery depending on the topography and accessibility to the avalanche path. Explosives are placed by hand, cable-pulley bomb trams, or with surplus military weapons. In addition to active avalanche control, WSDOT also uses passive control methods to control snow slides. These include snow sheds over the highway; elevated roadways so avalanches pass under them, or with catchment basins to stop the avalanche before snow reaches the highway. WSDOT also uses diversion dams and snow berms to keep the snow off the highway.

WSDOT avalanche control activity affects more than travelers. Backcountry recreation has become very popular. From the U.S. 2/Stevens Pass Ski Area, skiers and snowboarders can access backcountry areas and potentially venture into the highway avalanche zones. WSDOT posts warning signs at the top of the ski area and in key locations but are sometimes ignored. Besides risking injury, skiers and snowboarders sometimes trigger avalanches. They also create a hazard for themselves and others by hitchhiking back to the summit. When vehicles stop to give hitchhikers a ride, it creates a traffic hazard. The Washington State Patrol (WSP) petitioned WSDOT to post the avalanche zones from milepost 58 to 66 to prohibit hitchhiking and WSP troopers vigorously enforce this ban. Skiers and snowboarders face similar personal hazards at two Snoqualmie Pass ski areas when they ignore signs and venture outside ski area boundaries.

Recreational Activity Avalanche Control

Avalanches don't happen by accident and most human involvement is a matter of choice, not chance. Most avalanche accidents are caused by slab avalanches which are triggered by the victim or a member of the victim's party. However, any avalanche may cause injury or death and even small slides may be dangerous. Hence, always practice safe route-finding skills, be aware of changing conditions and carry avalanche rescue gear. Learn and apply avalanche terrain analysis and snow stability evaluation techniques to help minimize your risk. Remember that avalanche danger rating levels are only general guidelines. Distinctions between geographic areas, elevations, slope aspect and slope angle are approximate, and transition zones between dangers exist. No matter what the current avalanche danger, there are avalanche-safe areas in the mountains.



The Avalanche Danger Rose represents the highest danger level(s) expected for the indicated area (by elevation and aspect) for the daylight hours. The danger trend arrow (lower left part of rose graphic) indicates the most significant (highest impact) avalanche danger change expected for the daylight hours, ranging from strongly increasing (arrow pointing up) to strongly decreasing (arrow pointing down). Although the danger rose figures only indicate the greatest danger for the particular region for the daylight hours, danger trends for overnight hours are discussed in the text product. The danger rose can be visualized as a conical mountain within the forecast area that is divided into elevation rings and aspect slices as shown in the example. The first sample rose shown above with the mountain indicates an avalanche warning along with a strongly increasing danger trend and high danger above 4000 feet.

The second sample rose shown at right indicates two danger levels between 3000 feet (the outermost ring) and 7000 feet (the innermost ring). The danger is moderate in yellow and considerable in orange and indicates the following danger description: Considerable avalanche danger on northwest through northeast exposures above 4000 feet, otherwise moderate avalanche danger below 7000 feet. The slightly upward angled arrow in the left lower part of the figure indicates the most significant danger trend is for a slight danger increase during the day.

Avalanche Risk Assessment Methodology

Avalanche hazard risk assessment is based on avalanche forecast data available from U.S. Forest Service National Avalanche Center. Avalanche hazard values are derived from overlaying U.S. Forest Service National Avalanche Center forecast zones on the state map.

FIGURE A 1: AVALANCHE HAZARD (USFS NATIONAL AVALANCHE CENTER)

In Washington state, only some of the counties are at possible risk from avalanche events.

Area Exposure

Avalanche hazard area map was overlaid with the county map to estimate the percentage area exposed to avalanche hazards in each county. About 31 percent of the state area lies in avalanche hazard zones. These areas are primarily located in the upper elevations of the Cascades. Chelan, Skamania, Snohomish, Kittitas, King, Skagit, Whatcom, Pierce, Yakima, Lewis, Okanogan, Klickitat, Jefferson, Cowlitz, Clark, Clallam and Mason counties are the only counties exposed to major avalanche hazards. Some parts of Thurston and Douglas counties are also exposed to avalanche hazards.

In Chelan and Skamania counties, almost all of the county area is exposed to avalanche hazards. Significant areas (more than 50 percent) in Snohomish, Kittitas, Skagit, Whatcom, Pierce, Yakima and Lewis counties are also exposed to avalanche hazards.

Avalanche hazard exposure in concentrated in the Central Ecological Region. In Okanogan County 45-50 percent of the area is exposed to avalanche hazards. In Jefferson, Cowlitz, Clark and Clallam counties 20-35 percent of the county area is exposed to avalanche hazards.

Percentage of County Land Area with Avalanche Hazard Exposure	
County	Percent County Area in Avalanche Hazard Zone
Adams	0.00
Asotin	0.00
Benton	0.00
Chelan	96.51
Clallam	22.24
Clark	27.82
Columbia	0.00
Cowlitz	28.20
Douglas	0.04
Ferry	0.00
Franklin	0.00
Garfield	0.00
Grant	0.00
Grays Harbor	0.00
Island	0.00
Jefferson	34.93
King	64.67
Kitsap	0.00
Kittitas	66.55
Klickitat	46.53
Lewis	50.19
Lincoln	0.00
Mason	12.04
Okanogan	48.26
Pacific	0.00
Pend Oreille	0.00

Percentage of County Land Area with Avalanche Hazard Exposure	
County	Percent County Area in Avalanche Hazard Zone
Pierce	54.63
San Juan	0.00
Skagit	62.63
Skamania	91.53
Snohomish	67.36
Spokane	0.00
Stevens	0.00
Thurston	1.64
Wahkiakum	0.00
Walla Walla	0.00
Whatcom	57.53
Whitman	0.00
Yakima	50.96
Washington State	30.47

Population Exposure

Population exposure to avalanche hazard was estimated by overlaying the avalanche hazard layer over the 2011 developed areas derived from the land cover database. The 2017 estimated population for all census tracts was allocated to respective urban areas and the overlap with avalanche exposure was estimated using spatial analysis in Geographic Information System (GIS). While 31 percent of the state area is exposed to avalanche hazards, the population exposure is estimated to be less than three percent of the total estimated state population.

Almost 85 percent of the county population in Chelan County resides in areas exposed to avalanche hazards. More than 65,000 persons are estimated to reside in these areas in Chelan County. Another 62,000 persons are estimated to reside in areas exposed to avalanche hazards in King County. However, this constitutes less than three percent of the total county population. In Skamania County, more than 50 percent of the county population is located in areas with avalanche hazard exposure. In two counties — Okanogan and Skagit — about 10 percent of the county population is located in areas exposed to avalanche hazards. In other counties with avalanche risk, the population exposure is less than five percent of the county population.

Indirect exposure caused by avalanches crossing transportation corridors is discussed, but was not included within this assessment of population.

Population Exposure to Avalanche Hazard			
County	Total Population (2017 Estimates)	Percentage of Total State Population	Estimated County Population Exposed to Avalanche Hazards (in % values)
Adams	19870	0.27	0.00
Asotin	22290	0.30	0.00
Benton	193500	2.65	0.00
Chelan	76830	1.05	84.89
Clallam	74240	1.02	0.00
Clark	471000	6.44	0.16
Columbia	4100	0.06	0.00
Cowlitz	105900	1.45	3.45
Douglas	41420	0.57	0.17
Ferry	7740	0.11	0.00
Franklin	90330	1.24	0.00
Garfield	2200	0.03	0.00
Grant	95630	1.31	0.00
Grays Harbor	72970	1.00	0.00
Island	82790	1.13	0.00
Jefferson	31360	0.43	0.00
King	2153700	29.46	2.88
Kitsap	264300	3.62	0.00
Kittitas	44730	0.61	5.85
Klickitat	21660	0.30	2.80
Lewis	77440	1.06	0.90

Population Exposure to Avalanche Hazard			
County	Total Population (2017 Estimates)	Percentage of Total State Population	Estimated County Population Exposed to Avalanche Hazards (in % values)
Lincoln	10700	0.15	0.00
Mason	63190	0.86	0.00
Okanogan	42110	0.58	13.81
Pacific	21250	0.29	0.00
Pend Oreille	13370	0.18	0.00
Pierce	859400	11.76	1.25
San Juan	16510	0.23	0.00
Skagit	124100	1.70	10.09
Skamania	11690	0.16	56.11
Snohomish	789400	10.80	5.23
Spokane	499800	6.84	0.00
Stevens	44510	0.61	0.00
Thurston	276900	3.79	0.00
Wahkiakum	4030	0.06	0.00
Walla Walla	61400	0.84	0.00
Whatcom	216300	2.96	1.00
Whitman	48640	0.67	0.00
Yakima	253000	3.46	0.64
Washington State	7310300	100.00	2.96

Vulnerable Population Exposure

The social vulnerability index was created for each of the census tracts using American Community Survey (ACS) 2011-2016 five-year data. Social vulnerability data was first overlaid with developed areas extracted from the 2011 land cover database. Tract level social vulnerability estimates were assigned to respective developed areas in each of the tracts. This data was then overlaid with avalanche hazard layer to identify socially vulnerable developed areas that overlap with avalanche exposure.

Overall, a very small proportion (less than 0.1 percent) of the total state population is both ranked medium or higher on social vulnerability index and resides in areas exposed to avalanche hazard. These vulnerable populations are located in four counties – Chelan, Lewis, Okanogan and Yakima. Chelan County has most of this vulnerable population (about 300,000 persons) in avalanche hazard areas. However, this constitutes less than five percent of the total county population. Okanogan County also has almost five percent of the county population ranked medium or higher on social vulnerability index and located in areas with avalanche exposure. As such, avalanche hazard is not likely to be much of a concern with respect to significant direct impacts on vulnerable populations in the state.

Vulnerable Population Exposure to Avalanche Hazards			
County	Population (2017 Estimates)	Vulnerable Population in Areas with Avalanche Exposure	
		Vulnerable Population	% of Total County Population
Adams	0	0	0.00
Asotin	2817	0	0.00
Benton	10829	0	0.00
Chelan	4962	292628	3.81
Clallam	0	0	0.00
Clark	0	0	0.00
Columbia	0	0	0.00
Cowlitz	1357	0	0.00
Douglas	2996	0	0.00
Ferry	0	0	0.00
Franklin	0	0	0.00
Garfield	0	0	0.00
Grant	1172	0	0.00
Grays Harbor	0	0	0.00
Island	26218	0	0.00

Vulnerable Population Exposure to Avalanche Hazards			
County	Population (2017 Estimates)	Vulnerable Population in Areas with Avalanche Exposure	
		Vulnerable Population	% of Total County Population
Jefferson	0	0	0.00
King	582	0	0.00
Kitsap	64137	0	0.00
Kittitas	8805	0	0.00
Klickitat	5671	0	0.00
Lewis	163	42506	0.55
Lincoln	0	0	0.00
Mason	12609	0	0.00
Okanogan	14138	197625	4.69
Pacific	0	0	0.00
Pend Oreille	11175	0	0.00
Pierce	4512	0	0.00
San Juan	5529	0	0.00
Skagit	0	0	0.00
Skamania	3007	0	0.00
Snohomish	0	0	0.00
Spokane	61027	0	0.00
Stevens	8199	0	0.00
Thurston	194749	0	0.00
Wahkiakum	0	0	0.00
Walla Walla	240	0	0.00
Whatcom	0	0	0.00
Whitman	0	0	0.00
Yakima	6378	120826	0.48

Vulnerable Population Exposure to Avalanche Hazards			
County	Population (2017 Estimates)	Vulnerable Population in Areas with Avalanche Exposure	
		Vulnerable Population	% of Total County Population
Washington State	451273	672438	0.09

Built Environment Exposure

The built environment exposure to avalanche hazard is calculated using the general building stock data (2014) provided by the Federal Emergency Management Agency (FEMA) that contains the building values for all structures in the census tracts. General building stock values used in this analysis are the total structure value of all buildings (except agricultural) in each census tract in 2014 dollars. Building values for all occupancy types were summed for each census tract using only structure values (not content values) and assigned to the developed areas within each tract. These maps were then overlaid on the avalanche hazard layer to estimate the general building stock value within hazard exposure areas. Individual tract level estimates were aggregated to create the county level estimates.

Overall, less than three percent of the general building stock of the state is located in areas with exposure to avalanche hazard. King County has highest value (~$10.4 million) of general building stock value located in areas with avalanche exposure. In Chelan County, almost 85 percent of the general building stock value is in areas with avalanche exposure. In Skamania County, the avalanche hazard exposure of the building stock value is about 56 percent. Skagit and Okanogan counties also have marginally more than 10 percent of the county building stock value in areas exposed to avalanche hazards. In Lewis, Yakima, Douglas and Clark Counties, less than one percent of the building stock value is located in areas with avalanche hazard exposure.

Built Environment Exposure to Avalanche			
County	Total Value of General Building Stock (2014)	Exposed to Wildfires (Medium or higher)	
		Total Value of General Building Stock (2014)	Percent of Total County General Building Stock (2014)
Adams	$253,615	$0	0.00
Asotin	$1,061,235	$0	0.00
Benton	$6,529,565	$0	0.00
Chelan	$1,573,417	$1,335,752	84.89
Clallam	$2,427,219	$0	0.00
Clark	$32,074,170	$51,260	0.16
Columbia	$533	$0	0.00

Built Environment Exposure to Avalanche			
County	Total Value of General Building Stock (2014)	Exposed to Wildfires (Medium or higher)	
		Total Value of General Building Stock (2014)	Percent of Total County General Building Stock (2014)
Cowlitz	$4,992,730	$172,412	3.45
Douglas	$1,211,949	$2,110	0.17
Ferry	$1,521	$0	0.00
Franklin	$1,867,499	$0	0.00
Garfield	$437	$0	0.00
Grant	$583,022	$0	0.00
Grays Harbor	$1,162,104	$0	0.00
Island	$2,895,464	$0	0.00
Jefferson	$1,137,144	$0	0.00
King	$362,698,022	$10,454,375	2.88
Kitsap	$17,267,166	$0	0.00
Kittitas	$530,126	$31,023	5.85
Klickitat	$4,479	$126	2.80
Lewis	$1,402,914	$12,626	0.90
Lincoln	$87,198	$0	0.00
Mason	$608,531	$0	0.00
Okanogan	$59,252	$8,184	13.81
Pacific	$125,715	$0	0.00
Pend Oreille	$8,310	$0	0.00
Pierce	$62,547,883	$781,791	1.25
San Juan	$225,856	$0	0.00
Skagit	$5,389,339	$543,553	10.09
Skamania	$17,391	$9,758	56.11
Snohomish	$52,406,666	$2,739,377	5.23
Spokane	$31,281,088	$0	0.00
Stevens	$325,218	$0	0.00
Thurston	$9,798,392	$0	0.00
Wahkiakum	$1,649	$0	0.00
Walla Walla	$3,061,065	$0	0.00
Whatcom	$15,241,051	$151,816	1.00
Whitman	$1,385,430	$0	0.00
Yakima	$7,986,979	$50,837	0.64
Washington State	$630,231,344	$18,653,404	2.96

Critical Infrastructure Exposure

Critical infrastructure facilities that lie within the avalanche hazard areas are likely to be directly impacted by avalanche events. While the nature and degree of impact will largely depend on the magnitude of the event and the physical details of the facility, location within avalanche hazard exposure areas can enable prioritization of site specific hazard mitigation studies. The location of 12 critical infrastructure facilities including airports (23), dams (268), education facilities (5331), electric substations (1390), hospitals (147), power plants (146), public transit stations (60), railroad bridges (1619) and railway stations (317) were derived from the Homeland Security Foundation Level Database (HIFLD). This data was overlaid with the avalanche hazard exposure layer to identify facilities located in avalanche hazard areas. This analysis refers to point data and not critical infrastructure represented by a line such as roads and rail corridors. These networks will also be impacted by avalanche events, but due to data limitation they have not been included in this analysis.

Spatial analysis of this dataset reveals that only 13 percent of the critical infrastructure facilities in the state are located in areas exposed to avalanche hazard. Chelan County has the maximum number of critical infrastructure facilities (439) located in areas with avalanche exposure. In Kittitas County, 142 of the 303 critical infrastructure facilities are located in areas with avalanche exposure. In Skamania County 33 percent of the critical infrastructure facilities are located in areas exposed to avalanche hazards. In Okanogan County, approximately 29 percent of the critical infrastructure facilities are located in areas with avalanche exposure. In King County, 362 critical infrastructure facilities (13 percent) are located in areas with avalanche hazard exposure. While this analysis identifies critical facilities likely to be at risk from avalanche, it is important to note that specific risk to each facility results from the combination of the event characteristics (which are difficult to predict) and the site-level facility characteristics.

Indirect impacts to corridors bisecting avalanche runout areas, including Stevens Pass on U.S. Route 2 and Snoqualmie Pass on Interstate 90, were discussed above, but were not included within this specific analysis of critical facility exposure.

Critical Infrastructure Exposure			
County	Number of Critical Infrastructure Facilities	In Avalanche Hazard Exposure Areas	
		Number of Critical Infrastructure Facilities	Percent of Critical Infrastructure Facilities
Adams	206	0	0.00
Asotin	81	0	0.00
Benton	664	0	0.00
Chelan	507	439	86.59
Clallam	273	4	1.47
Clark	490	36	7.35

Critical Infrastructure Exposure			
County	Number of Critical Infrastructure Facilities	In Avalanche Hazard Exposure Areas	
		Number of Critical Infrastructure Facilities	Percent of Critical Infrastructure Facilities
Columbia	88	0	0.00
Cowlitz	474	23	4.85
Douglas	290	0	0.00
Ferry	83	0	0.00
Franklin	270	0	0.00
Garfield	89	0	0.00
Grant	501	0	0.00
Grays Harbor	377	0	0.00
Island	104	0	0.00
Jefferson	197	2	1.02
King	2761	362	13.11
Kitsap	451	0	0.00
Kittitas	303	142	46.86
Klickitat	322	45	13.98
Lewis	374	73	19.52
Lincoln	237	0	0.00
Mason	152	0	0.00
Okanogan	359	104	28.97
Pacific	152	0	0.00
Pend Oreille	69	0	0.00
Pierce	1130	126	11.15
San Juan	98	0	0.00
Skagit	474	63	13.29
Skamania	145	48	33.10
Snohomish	787	124	15.76

Critical Infrastructure Exposure			
County	Number of Critical Infrastructure Facilities	In Avalanche Hazard Exposure Areas	
		Number of Critical Infrastructure Facilities	Percent of Critical Infrastructure Facilities
Spokane	933	0	0.00
Stevens	211	0	0.00
Thurston	462	3	0.65
Wahkiakum	17	0	0.00
Walla Walla	273	0	0.00
Whatcom	613	66	10.77
Whitman	409	0	0.00
Yakima	601	60	9.98
Washington State	16027	1720	10.73

State Operations and Facilities Exposure

The list of state-owned (9415) and leased facilities (1039) was obtained from 2017 Facilities Inventory System Report produced by Office of Financial Management (detailed list included in Appendix I-2). These facilities were geo-located based on the addresses provided in the facilities inventory report and then overlaid with avalanche hazard layer.

The spatial analysis reveals that about 5 percent of the state-owned facilities are located in areas with avalanche exposure. King County has the highest number (88) of facilities located in areas with avalanche hazard exposure. Pierce County has 78 of its 864 state-owned facilities located in area with avalanche hazard exposure. However, in both counties, these facilities constitute less than 10 percent of the state-owned facilities located in the county. In Chelan County, which has the largest proportion of the county area exposed to landslides, only 12.5 percent of the state-owned facilities are located in areas with avalanche exposure. Overall, less than one percent of the state-leased facilities are located in areas exposed to avalanche hazards.

State Owned and Leased Facilities Exposure						
County	State Owned Facilities	State Leased Facilities	In areas Exposed to Avalanche Hazard			
			State Owned Facilities	Percent of State Owned Facilities	State Leased Facilities	Percent of State Leased Facilities
Adams	64	1	0	0.00	0	0.00
Asotin	90	6	0	0.00	0	0.00
Benton	159	30	0	0.00	0	0.00
Chelan	192	22	24	12.50	0	0.00
Clallam	183	12	0	0.00	0	0.00
Clark	229	23	21	9.17	0	0.00
Columbia	75	1	0	0.00	0	0.00
Cowlitz	128	18	16	12.50	0	0.00
Douglas	42	10	5	11.90	1	10.00
Ferry	32	3	0	0.00	0	0.00
Franklin	160	9	0	0.00	0	0.00
Garfield	21	0	0	0.00	0	0.00
Grant	252	15	0	0.00	0	0.00
Grays Harbor	224	13	0	0.00	0	0.00
Island	269	6	0	0.00	0	0.00
Jefferson	394	5	0	0.00	0	0.00
King	1120	226	88	7.86	0	0.00
Kitsap	269	15	0	0.00	0	0.00
Kittitas	348	11	30	8.62	1	9.09
Klickitat	110	10	10	9.09	0	0.00
Lewis	163	13	14	8.59	0	0.00
Lincoln	58	0	0	0.00	0	0.00
Mason	244	7	0	0.00	0	0.00
Okanogan	179	10	24	13.41	0	0.00
Pacific	233	6	0	0.00	0	0.00

State Owned and Leased Facilities Exposure

County	State Owned Facilities	State Leased Facilities	In areas Exposed to Avalanche Hazard			
			State Owned Facilities	Percent of State Owned Facilities	State Leased Facilities	Percent of State Leased Facilities
Pend Oreille	18	5	0	0.00	0	0.00
Pierce	865	54	78	9.02	0	0.00
San Juan	282	5	0	0.00	0	0.00
Skagit	286	15	29	10.14	1	6.67
Skamania	64	2	7	10.94	0	0.00
Snohomish	270	71	19	7.04	0	0.00
Spokane	571	121	0	0.00	0	0.00
Stevens	65	7	0	0.00	0	0.00
Thurston	431	166	0	0.00	0	0.00
Wahkiakum	22	0	0	0.00	0	0.00
Walla Walla	159	11	0	0.00	0	0.00
Whatcom	283	32	27	9.54	1	3.13
Whitman	566	9	0	0.00	0	0.00
Yakima	294	61	25	8.50	1	1.64
Washington State	9415	1031	417	4.43	5	0.48

First Responder Facilities Exposure

Locations of fire stations, law enforcement buildings and emergency medical stations in the state were identified from the Homeland Security Foundation Level Database (HIFLD). Using ESRI ArcMap geocoding services, 1,268 fire stations, 332 law enforcement agencies and 1,162 emergency medical service (EMS) stations (including those co-located with fire stations) were located on the state map.

It is estimated that 10 percent of the fire stations, four percent of the law enforcement buildings and 10 percent of the EMS facilities are located in areas with avalanche hazard exposure. In Chelan County almost 84 percent of all fire stations (25), 100 percent of law enforcement buildings (3), and 86% of EMS facilities (18) are located in areas with avalanche hazard exposure. In Kittitas County, 19 of the 33 fire stations, one of the six law enforcement buildings and 18 of the 33 EMS facilities are located in areas with avalanche hazard exposure. Overall, the risk to first responder facilities from avalanche hazards is likely to be low because most of these facilities are located outside of the avalanche exposure areas.

First Responder Facilities Exposure to Avalanche Hazard

County	Fire Station			Law Enforcement			EMS		
	Total Number of Facilities	In areas Exposed to Avalanche		Total Number of Facilities	In areas Exposed to Avalanche		Total Number of Facilities	In areas Exposed to Avalanche	
		Number of facilities	Percent Facilities		Number of facilities	Percent Facilities		Number of facilities	Percent Facilities
Adams	11	0	0.00	4	0	0.00	5	0	0.00
Asotin	3	0	0.00	4	0	0.00	2	0	0.00
Benton	29	0	0.00	7	0	0.00	27	0	0.00
Chelan	30	25	83.33	3	3	100.00	21	18	85.71
Clallam	22	0	0.00	5	0	0.00	24	0	0.00
Clark	40	4	10.00	13	0	0.00	40	4	10.00
Columbia	3	0	0.00	1	0	0.00	2	0	0.00
Cowlitz	25	4	16.00	8	0	0.00	17	0	0.00
Douglas	12	0	0.00	3	0	0.00	8	0	0.00
Ferry	12	0	0.00	3	0	0.00	5	0	0.00
Franklin	20	0	0.00	7	0	0.00	15	0	0.00
Garfield	2	0	0.00	1	0	0.00	1	0	0.00
Grant	50	0	0.00	15	0	0.00	28	0	0.00
Grays Harbor	32	0	0.00	9	0	0.00	20	0	0.00
Island	10	0	0.00	4	0	0.00	9	0	0.00
Jefferson	12	0	0.00	4	0	0.00	13	0	0.00
King	159	17	10.69	60	3	5.00	161	17	10.56
Kitsap	47	0	0.00	6	0	0.00	49	0	0.00
Kittitas	33	19	57.58	6	1	16.67	33	18	54.55
Klickitat	36	14	38.89	3	0	0.00	25	11	44.00

First Responder Facilities Exposure to Avalanche Hazard

County	Fire Station			Law Enforcement			EMS		
	Total Number of Facilities	In areas Exposed to Avalanche		Total Number of Facilities	In areas Exposed to Avalanche		Total Number of Facilities	In areas Exposed to Avalanche	
		Number of facilities	Percent Facilities		Number of facilities	Percent Facilities		Number of facilities	Percent Facilities
Lewis	51	11	21.57	12	2	16.67	50	9	18.00
Lincoln	10	0	0.00	4	0	0.00	9	0	0.00
Mason	46	0	0.00	3	0	0.00	47	0	0.00
Okanogan	27	5	18.52	7	2	28.57	17	3	17.65
Pacific	16	0	0.00	5	0	0.00	10	0	0.00
Pend Oreille	18	0	0.00	1	0	0.00	16	0	0.00
Pierce	99	12	12.12	29	1	3.45	101	13	12.87
San Juan	4	0	0.00	1	0	0.00	5	0	0.00
Skagit	39	2	5.13	6	0	0.00	40	3	7.50
Skamania	3	1	33.33	2	0	0.00	3	1	33.33
Snohomish	74	8	10.81	23	1	4.35	73	7	9.59
Spokane	52	0	0.00	10	0	0.00	50	0	0.00
Stevens	34	0	0.00	6	0	0.00	27	0	0.00
Thurston	47	0	0.00	17	0	0.00	55	0	0.00
Wahkiakum	9	0	0.00	1	0	0.00	5	0	0.00
Walla Walla	21	0	0.00	3	0	0.00	20	0	0.00
Whatcom	50	2	4.00	10	0	0.00	54	2	3.70
Whitman	24	0	0.00	8	0	0.00	22	0	0.00
Yakima	56	6	10.71	18	1	5.56	53	6	11.32
Washington State	1268	130	10.25	332	14	4.22	1162	112	9.64

Washington State Risk Index for Avalanche (WaSRI-A)

The avalanche risk index (WaSRI-A) for each county is estimated as the average of the standardized rank of avalanche exposure of county area, of population exposure, vulnerable populations, built environment, critical infrastructure facilities, state facilities and first responder facilities. The individual exposure assessment values were categorized into five classes (1: Low, 2: Medium-Low, 3: Medium, 4: Medium-High, and 5: High) using z-score transformation (standard deviations from the mean).

Classification Schema for Standardized Exposure Assessment Values	
Standard Deviation	Classification Rank
0.50 to 1.0	Medium-High (4)
0.5 to -0.5	Medium (3)
-0.5 to -1	Medium-Low (2)
< -1.0	Low (1)

The avalanche risk index (WaSRI-A) is the mean of these individual exposure rankings. While similar assessments were also done for economic consequences and risk to environment (described in the next sections) these specific rankings were not included in the estimation of the risk index. Economic consequence rankings were not included because of data quality limitations. Economic consequences estimates are based on overall county data. Including them in the index is likely to result in biased estimation of landslide risk. The natural environment assessment includes a limited number of environmental resources. Each natural hazard is associated with specific effects on the natural environment and therefore adoption of a common evaluation approach across all-hazard types for environmental impacts is not appropriate.

The statistical analysis of wildfire exposure assessments reveals that four counties – Chelan, Kittitas, Okanogan and Skamania counties are at the highest risk from avalanche hazards. All of these counties, except for Okanogan County, have high proportion of county area (ranked high) located in areas exposed to avalanche hazard. The proportion of population exposed to avalanche hazards in these five counties is ranked high, except for Kittitas, wherein the population exposure to avalanche is ranked medium-high. Only two counties, Okanogan ad Chelan, are ranked high for vulnerable population exposure to volcanoes, the other three are ranked only at medium.

Four counties – Klickitat, Lewis, Skagit and Snohomish are ranked at medium-high for avalanche hazards. While the exposure assessment across all variables predominantly ranges from medium to medium-high for most of the categories, high vulnerable population exposure is estimated in Lewis County among this group. Yakima County, ranked medium-low on the overall avalanche risk hazard index, is ranked high on the vulnerable population exposure category. A number of counties have no exposure to avalanche risk and as such have not been ranked on the index.

Avalanche Risk Index (WaSRI A) and Constituent Avalanche Exposure Ranks for Each County

County	Area	Population	Vulnerable Population	Built Environment	Critical Infrastructure	State Facilities	First Responder Facilities	Avalanche Risk Index (WaSRI A)
Adams								
Asotin								
Benton								
Chelan	High	High	High	High	High	High	High	HIGH
Clallam	Medium-Low	Low	Medium	Low	Medium-Low	Low	Low	LOW
Clark	Medium-Low	Medium-Low	Medium	Medium-Low	Medium-Low	Medium	Medium	MEDIUM-LOW
Columbia								
Cowlitz	Medium-Low	Medium-High	Medium	Medium-High	Medium-Low	High	Medium	MEDIUM
Douglas	Low	Medium-Low	Medium	Medium-Low	Low	High	Low	MEDIUM-LOW
Ferry								
Franklin								
Garfield								
Grant								
Grays Harbor								
Island								
Jefferson	Medium-Low	Low	Medium	Low	Medium-Low	Low	Low	LOW
King	Medium-High	Medium-High	Medium	Medium-High	Medium	Medium-Low	Medium	MEDIUM
Kitsap								

Avalanche Risk Index (WaSRI A) and Constituent Avalanche Exposure Ranks for Each County

County	Area	Population	Vulnerable Population	Built Environment	Critical Infrastructure	State Facilities	First Responder Facilities	Avalanche Risk Index (WaSRI A)
Kittitas	High	Medium-High	Medium	Medium-High	High	Medium-High	High	HIGH
Klickitat	Medium	Medium	Medium	Medium	Medium-High	Medium	High	MEDIUM-HIGH
Lewis	Medium	Medium	High	Medium	Medium-High	Medium	Medium-High	MEDIUM-HIGH
Lincoln								
Mason	Low	Low	Medium	Low	Low	Low	Low	LOW
Okanogan	Medium	High	High	High	High	High	Medium-High	HIGH
Pacific								
Pend Oreille								
Pierce	Medium-High	Medium	Medium	Medium	Medium	Medium	Medium-High	MEDIUM
San Juan								
Skagit	Medium-High	High	Medium	High	Medium-High	Medium-High	Medium-Low	MEDIUM-HIGH
Skamania	High	High	Medium	High	High	Medium-High	High	HIGH
Snohomish	High	Medium-High	Medium	Medium-High	Medium-High	Medium-Low	Medium	MEDIUM-HIGH
Spokane								
Stevens								
Thurston	Low	Low	Medium	Low	Low	Low	Low	LOW
Wahkiakum								

Avalanche Risk Index (WaSRI A) and Constituent Avalanche Exposure Ranks for Each County

County	Area	Population	Vulnerable Population	Built Environment	Critical Infrastructure	State Facilities	First Responder Facilities	Avalanche Risk Index (WaSRI A)
Walla Walla								
Whatcom	Medium-High	Medium	Medium	Medium	Medium	Medium -High	Medium-Low	MEDIUM
Whitman								
Yakima	Medium	Medium-Low	High	Medium-Low	Medium	Medium -Low	Medium-High	MEDIUM-LOW

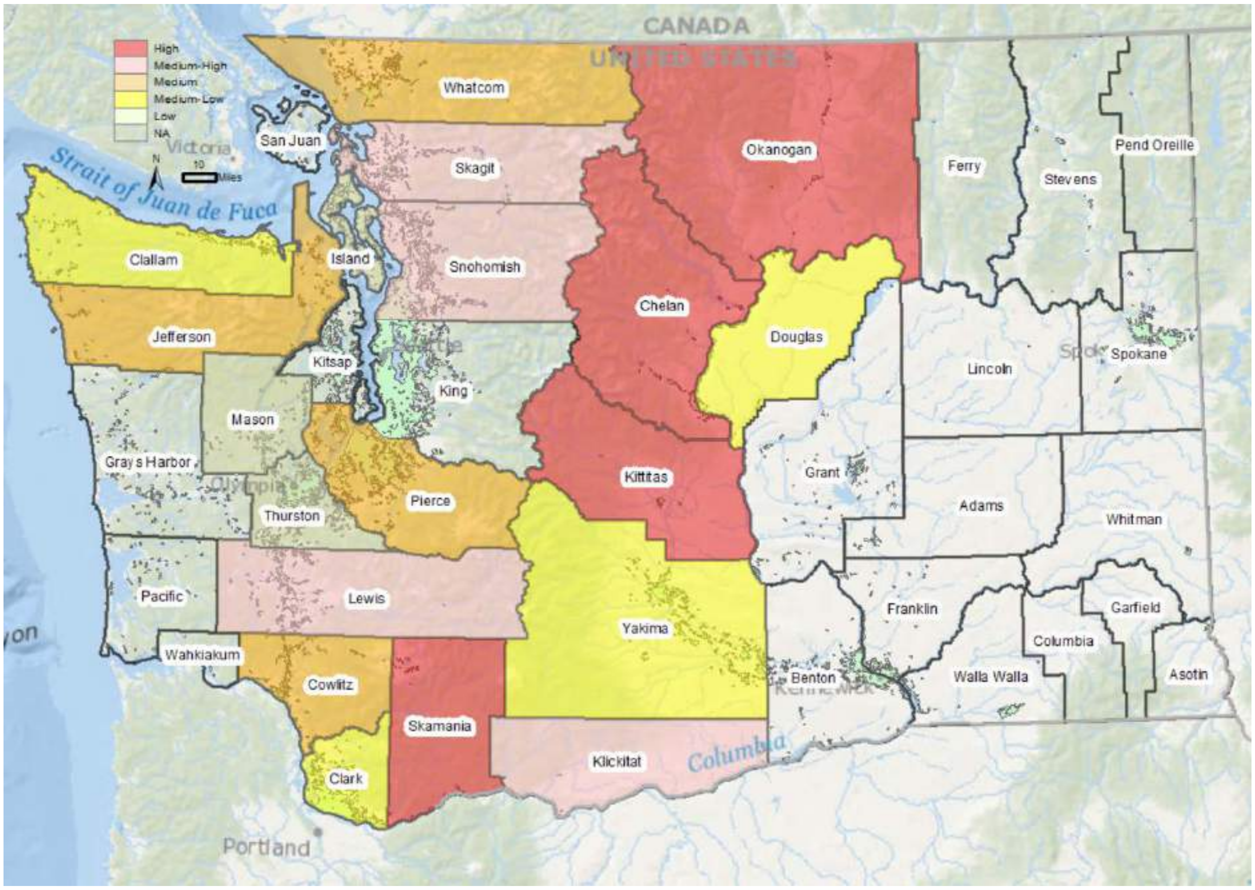


FIGURE A 2: AVALANCHE RISK DISTRIBUTION (WASRI-A)

Economic Consequences

The economic activity data was derived from National Association of Counties. This dataset provides the county level estimates of Gross Domestic Product (GDP) for 2016. The four counties ranked high on the avalanche risk index contribute less than one percent of the state GDP. Among the top three contributors to state GDP — King, Pierce and Snohomish counties — Snohomish county is ranked medium-high for avalanche risks. The other two are ranked at medium for the avalanche risk index. Therefore, it is expected that major avalanche events are likely to have only a limited economic impact.

Avalanche Risk (WaSRI V) and County GDP 2016		
County	**Landslide Risk Index (WaSRI L)**	**GDP 2016 (in Mil.)**
Adams		$746.07
Asotin		$618.43
Benton		$10,627.85
Chelan	HIGH	$4,363.01
Clallam	LOW	$2,573.06
Clark	MEDIUM-LOW	$18,682.64
Columbia		$144.20
Cowlitz	MEDIUM	$4,474.88
Douglas	MEDIUM-LOW	$1,037.39
Ferry		$198.13
Franklin		$3,356.16
Garfield		$97.44
Grant		$3,803.65
Grays Harbor		$2,237.44
Island		$2,796.80
Jefferson	LOW	$867.23
King	MEDIUM	$230,344.61
Kitsap		$12,082.18
Kittitas	HIGH	$1,566.21
Klickitat	MEDIUM-HIGH	$1,004.05
Lewis	MEDIUM-HIGH	$2,573.06
Lincoln		$347.25
Mason	LOW	$1,566.21

Avalanche Risk (WaSRI V) and County GDP 2016		
County	**Landslide Risk Index (WaSRI L)**	**GDP 2016 (in Mil.)**
Okanogan	HIGH	$1,678.08
Pacific		$637.45
Pend Oreille		$354.63
Pierce	MEDIUM	$41,280.80
San Juan		$602.88
Skagit	MEDIUM-HIGH	$5,705.48
Skamania	HIGH	$218.04
Snohomish	MEDIUM-HIGH	$39,378.97
Spokane		$24,723.73
Stevens		$1,111.56
Thurston	LOW	$12,865.29
Wahkiakum		$93.41
Walla Walla		$2,908.67
Whatcom	MEDIUM	$10,068.49
Whitman		$2,237.44
Yakima	MEDIUM-LOW	$10,404.10

Risk to Environment

To assess the risk to environmental resources, the spatial land cover mapped data was overlaid with avalanche hazard layer. Forests, scrubland, wetland and cropland areas were identified as environmentally critical areas. The overlap between these areas of ecological importance and avalanche hazard areas was analyzed through spatial analysis in GIS software. It is estimated that 32 percent of the state’s environmentally critical resources are also at medium or higher wildfire exposure. The high degree of overlap among the ecologically critical resources is expected most of the avalanche hazard lie with the ecological diverse central region of the state. The spatial analysis reveals that more than 80 percent of the environmentally sensitive areas in King County are exposed to avalanche hazards. In Chelan and Skamania counties, more than 90 percent of the county ecologically sensitive areas are also exposed to avalanche hazards. In Snohomish, Pierce, Kittitas, Whatcom, Skagit, Yakima and Lewis counties, more than 50 percent of the environmentally critical areas are in avalanche exposure areas.

Environmentally Critical Areas at Risk from Avalanche	
County	**Percent of County Ecologically Critical Area with Avalanche Exposure**
Adams	0.00
Asotin	0.00
Benton	0.00
Chelan	96.80
Clallam	22.73
Clark	33.79
Columbia	0.00
Cowlitz	28.97
Douglas	0.02
Ferry	0.00
Franklin	0.00
Garfield	0.00
Grant	0.00
Grays Harbor	0.00
Island	0.00
Jefferson	37.21
King	81.56
Kitsap	0.00
Kittitas	66.77
Klickitat	47.50
Lewis	50.83
Lincoln	0.00
Mason	13.16
Okanogan	48.38
Pacific	0.00
Pend Oreille	0.00

Environmentally Critical Areas at Risk from Avalanche	
County	**Percent of County Ecologically Critical Area with Avalanche Exposure**
Pierce	68.07
San Juan	0.00
Skagit	62.66
Skamania	92.37
Snohomish	73.88
Spokane	0.00
Stevens	0.00
Thurston	1.86
Wahkiakum	0.00
Walla Walla	0.00
Whatcom	65.31
Whitman	0.00
Yakima	51.60
Washington State	31.39

Climate Change Risk Profile

Washington state experiences relatively wet winters and dry summers, with locations west of the Cascade Range considerably wetter than the sometimes desert-like conditions on the east side. In addition, the long, Pacific and Puget sound coastline supports a variety of coastal environments. Overall, Washington's diverse climate and landscape make it one of the most ecologically rich areas in the United States, a feature that has been integral to sustaining the region's economy, culture and way of life.

When it comes to anticipating the impacts of climate change on natural hazards, it is often difficult to estimate the impacts of changing climatic conditions on local hazard characteristics. The degree and nature of changes that are likely to happen in the global climatic system are to a large extent dependent on the ultimate levels of concentration of greenhouse gases in the atmosphere.

This itself is dependent on numerous variables including the choice of development pathways that millions of communities around the world choose to follow. Therefore, understanding and quantifying the implications of a changing climate are complex and challenging. This requires detailed information about the magnitude of changes in the local environment, including information on changes in natural resource availability, on behavioral responses to these climate-induced changes, and on changes that may occur beyond the state of Washington.

The climate change community refers to the sequestering of greenhouse gasses as mitigation while managing the impacts of climate change is referred to as adaptation. Hazards mitigation as used by emergency managers is often used as a synonym for climate adaption.

Successful implementation of climate mitigation and adaptation policies, not only in the state of Washington but also across the world, may significantly influence local climate change impacts. Therefore, it is important that any discussion of future climate change impacts be treated as only one of the plausible future outcomes. Locally, it could be much worse or not that bad, depending upon how successful communities across the world are at applying climate mitigation measures, and how successful local communities are at adapting.

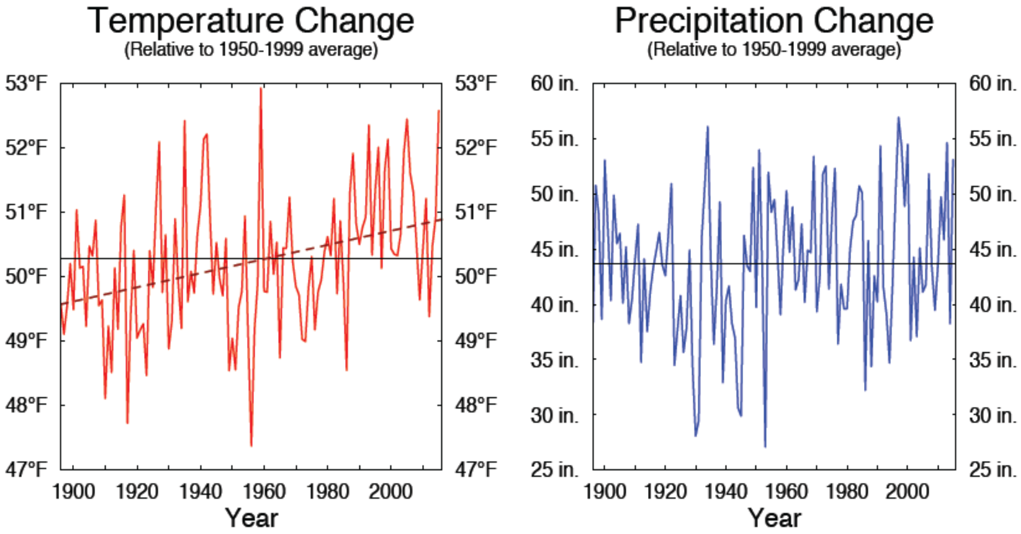
At the same there is increasing scientific evidence that some changes in the extreme weather events are already underway (Parmesan and Yohe 2003). The general increase in global mean temperatures has resulted in a rise in the number of hot days, and a decrease in number of cold/frost days (USGCRP 2009). Changes in temperature extremes can be predicted with high degree of confidence, but projections on the rate of change is subject to uncertainty, based on the present state of climate change science. It is not so much seas will become 10 feet higher along our Washington coasts, for instance, it is more a matter of when. There is also considerable certainty that our changing climate is and will continue to increase the frequency of thunderstorms, tornadoes and lighting. There are no reliable models to project localized these hazard events. In summary, questions and great deal of uncertainty remains in regard to the local impacts of changing climatic conditions.

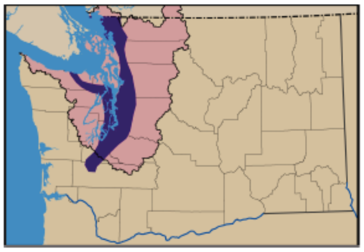
A recent report “Climate Change in the Northwest,” (Bethel et al. 2013) published as one of a series of technical inputs to the Third National Climate Assessment (NCA) report, provides a good summary of the impacts that may be expected in Washington state. The report affirms that climate variability and change in the Northwest is influenced by both global and local factors, such as the El Niño-Southern Oscillation and mountain ranges

As per the available climatic data, during 1895–2011, the Northwest warmed approximately 0.7 °C (1.3 °F), while precipitation fluctuations do not seem to show any consistent [annual] tendency (Bethel et al 2013). The frequency of extreme high night-time minimum temperatures increased in the Northwest during 1901–2009 but observed changes in extreme precipitation are ambiguous. Under most development scenarios, the Northwest is expected to experience an increase in temperature year-round with more warming in summer and little change in annual precipitation, with most models projecting decreases for summer and increases during the other seasons. Multiple climate change models predict that an increase in temperature and precipitation extremes in the Northwest.

In a Washington Department of Ecology publication, “Preparing for a Changing Climate: Washington State's Integrated Climate Response Strategy”, the department offers nine key indicators and projections of climate change affecting Washington. These include

1. Increasing carbon dioxide levels.
2. Warmer air temperatures.
3. Drier summers and reduced snowfall.
4. More frequent and severe and extreme weather events.
5. Rising sea levels.
6. More acidic marine waters.
7. Warmer water temperatures.
8. Increasing frequency and severity of wildfires.
9. Increasing Preparations for a Changing Climate: Washington state's Integrated Climate Response Strategy frequency and severity of flooding.





Temperature is rising in the Puget Sound lowlands, and there is no long term trend in precipitation. Average annual air temperature (top left, red, in °F) and total annual precipitation (top right, blue, in %) for the Puget Sound Lowlands climate division[D] (dark blue shading in map), shown relative to the average for 1950-1999 (black horizontal line in both graphs, corresponding to 50.3°F for annual aveage temperature and 43.6 inches for annual total precipitation). The dashed line in the temperature plot is the fitted trend, indicating a warming of +1.3°F (range: +0.7°F to +1.9°F)[B] from 1895 to 2014. The trend for precipitation is not statistically significant, and therefore is not shown. *Data source: Vose et al. 2014.*[D,1]

Figure CC 1: Overview of Climatic Changes in the Region (Source: As illustrated in State of Knowledge: Climate Change in Puget Sound: Prepared by the Climate Impacts Group University of Washington November 2015

A little physics

Weather can be thought of as work and the more energy in the atmosphere the more work produced in the form of weather. The more energy, the more probable occurrences of extreme weather.

This is basic physics. Heat energy can change forms and drive different weather events. The more energy, the greater possible variance in the weather. You change energy properties every day. Think of your car using:

- heat from a confined explosion in your car's engine,
- to expand a volume of gas, that,
- pushes a piston up and down that,
- turns a generator that,
- creates electricity that,
- Power your headlights.
- Every time you drive your car, energy changes form many times. In this case the more heat the brighter the headlight.

Similarly, atmospheric energy:

- heats the ocean that
- creates more water vapor in the air, that
- result in more rain that
- falls on to the Snoqualmie watershed that
- flows over its banks on to the floodplain that
- threatens to flood Colleen Johnson's house but fortunately she elevated her house way back in 1986 with the help of FEMA and the Small Business Administration.

The more heat trapped in the atmosphere, the greater the chance that the added energy from global warming will result in more frequent and intense rainfall and flooding within the Snoqualmie basin, and the happier Colleen will be that she elevated her house.

We can think of this process as our weather being a radio having a grand volume dial, a climate directed rheostat, where global warming is turning up the volume and all atmospheric systems are given a little more energy.

This added energy in the atmosphere goes somewhere, and that somewhere can be realized in stronger winds, more hail storms, greater rain intensity. And, we, along with other living things, must learn to adapt.

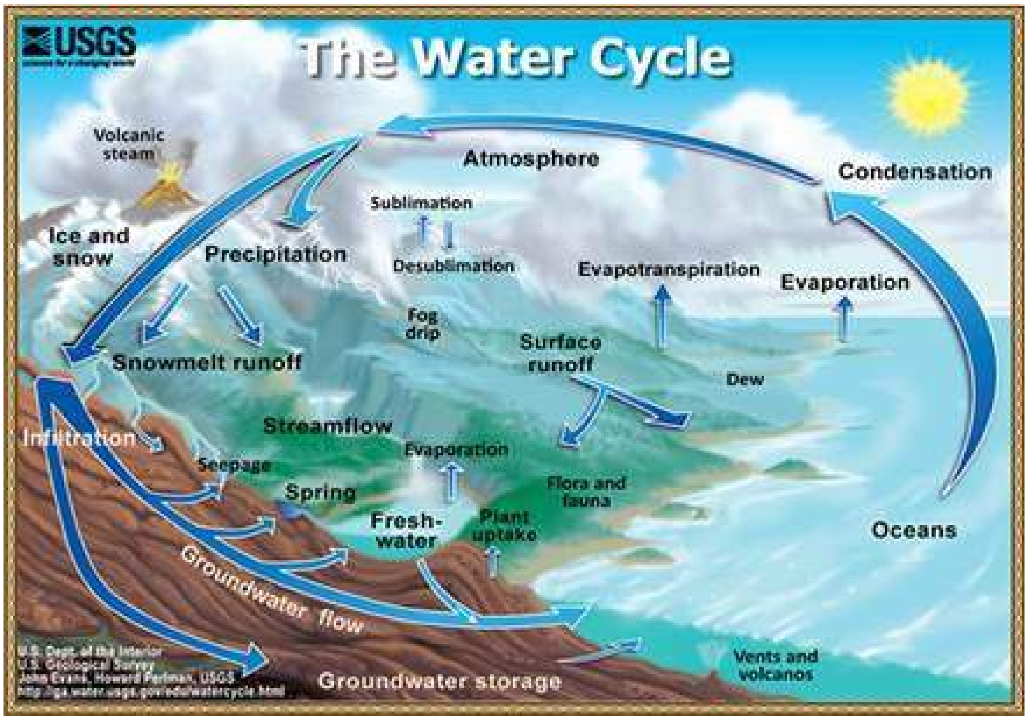


FIGURE CC 2: THE WATER CYCLE (USGS)

Impact on Droughts and Floods

Changes in precipitation and increasing air temperatures are already having, and will continue to have, significant impacts on hydrology and water resources. Such climate changes will alter streamflow magnitude and timing, water temperatures, and water quality.

Since about 1950, average Cascade Mountains snowpack on April 1 decreased about 20 percent (Mote 2006), spring snowmelt occurred up to 30 days earlier depending on location (Stewart et al 2005), late winter/early spring streamflow increases ranged from 0 percent to greater than 20 percent as a fraction of annual flow (Hidalgo et al 2009), and summer flow decreased 0 percent to 15 percent as a fraction of annual flow, with exceptions in smaller areas and shorter time periods (Mote et al 2008). Hydrologic impacts will vary by watershed type. Snow-dominant watersheds are projected to shift toward mixed rain-snow conditions, resulting in earlier and reduced spring peak flow, increased winter flow, and reduced late-summer flow. Mixed rain-snow watersheds are projected to shift toward rain-dominant conditions; and rain-dominant watersheds could experience higher winter stream flows if winter precipitation increases, but little change in streamflow timing.

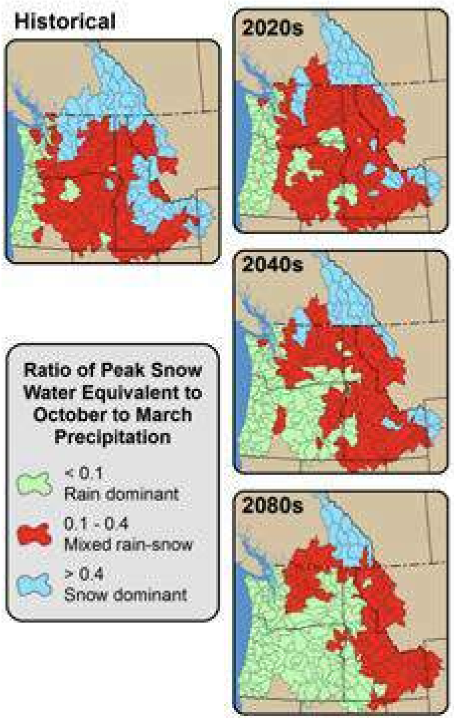


FIGURE CC3: NW WATERSHED CLASSIFICATION

The classification of NW watersheds into rain dominant, mixed rain/snow and snow/melt dominant and how these watersheds are expected to change as a result of climate warming based on SRES-A1B scenario of continued growth of greenhouse gas emissions peaking at mid-century (Hamlet et al 2013) as illustrated in *State of Knowledge:* **Climate Change in Puget Sound**: *Prepared by the* Climate Impacts Group University of Washington November 2015

It is likely that water budgeting will become increasingly difficult with increasingly low annual stream flows. Changing climatic conditions will translate into greater uncertainty for water users and supply system operators (Stewart et al 2005). Most irrigation supply systems have less than a year of storage, and a very few have multi-year storage capacity. With dry years becoming drier, more users will be affected, and users who have rarely been limited before may have to stop withdrawing water more frequently. Another study identified strong correlations between annual and summer flows over most of the region, suggesting that diversions on streams without upstream storage will face more severe shortages as well, and more users of such systems will be cut off earlier in the summer (Luce and Holden 2009).

Reduced water supply combined with increased water demands in the summer could lead to reduction in the proportion of irrigable cropland and the value of agricultural production. Overall more frequent and severe droughts are likely. Some basins may also experience increases in extreme precipitation and flooding. Increased winter flood risk is likely in mixed rain-snow basins in Washington from warmer winter temperatures and increased precipitation variability.

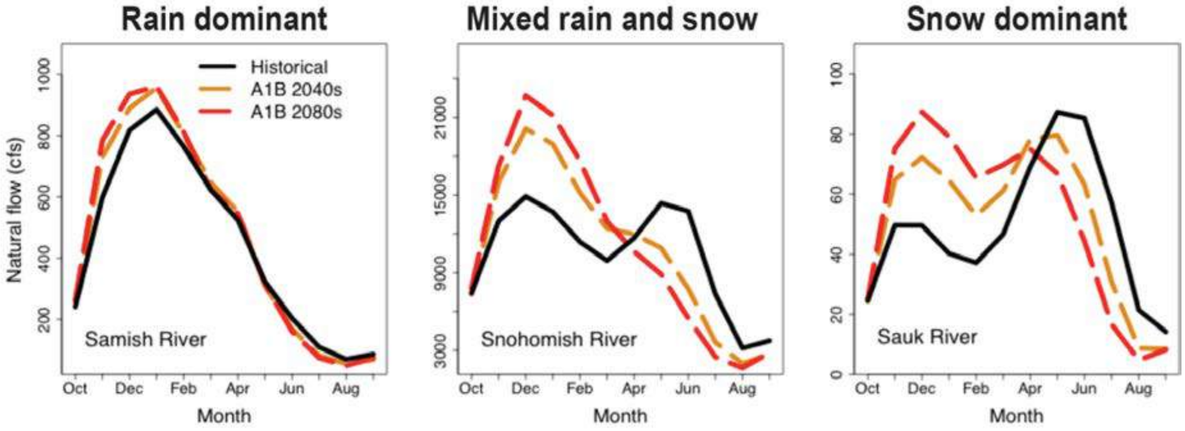


FIGURE CC 4: EXPECTED CHANGES IN RIVER FLOWS (SOURCE: STATE OF KNOWLEDGE: CLIMATE CHANGE IN PUGET SOUND: PREPARED BY THE CLIMATE IMPACTS GROUP UNIVERSITY OF WASHINGTON NOVEMBER, 2015)

Impact on Coastal Communities

Northwest coastal cities face multiple climate impacts and risks, including sea level rise, erosion, and flooding. Based on multiple climate change assessment models, sea level along the Northwest coast is projected to rise 4–56” (9–143 cm) by 2100, with significant local variations. End-of-century sea level rise projections for Washington state released in 2008 show relative sea level changes ranging from a small drop of a few decimeters (resulting from tectonic uplift along the NW portion of the Olympic Peninsula outpacing sea level rise) to a net increase in water levels of 128 cm (50 in) in the Puget Sound (Mote et al. 2008).

It is assumed that increasing wave heights in recent decades have been a dominant factor in the observed increased frequency of coastal flooding along the outer coast and are likely to continue to be more so due to changing climatic conditions. Regional sea levels are expected to rise up to 12 inches (30.5 cm) during an El Niño event, compounding impacts of sea level rise. However, it is unknown whether and how El Niño-Southern Oscillation (ENSO) intensity and frequency may change in the future.

Ocean temperatures off the Northwest coast have increased in the past and, though highly variable, are likely to increase in the future, causing shifts in distribution of marine species and contributing to more frequent and harmful algal blooms. Timmermann et al. (1999) suggest that future sea surface temperatures in the tropical Pacific are likely to resemble present-day EI Nino conditions. Another study (Griggs and Brown 1998), analyzing severe EI Nino events between 1982 and 1998, eastern Pacific winter storms tracked farther south than in previous years causing extensive wave and storm damage, coastal erosion, and flooding along the Pacific Northwest coast.

Sea level rise and flooding will also adversely affect Northwest coastal transportation infrastructure, though the degree of potential impacts will vary. About 2,800 miles of roads in Washington and Oregon coastal counties are in the 100-year floodplain. A 2011 study by Washington State Department of Transportation assessed the climate change vulnerability of state-owned transportation infrastructure, identifying some outer coast and low-lying highways near Puget Sound that may face long-term inundation from 2 feet (0.6 m) of sea level rise (WSDOT 2011). The report concluded that most major state highways in Washington are situated high enough to experience only temporary closures.

PROCESSES CAUSING SEA LEVELS TO RISE

- Ocean warming or thermal expansion
- Melting of land-based glaciers
- Melting of Antarctic and Greenland ice sheets
- Tectonics and vertical land movements

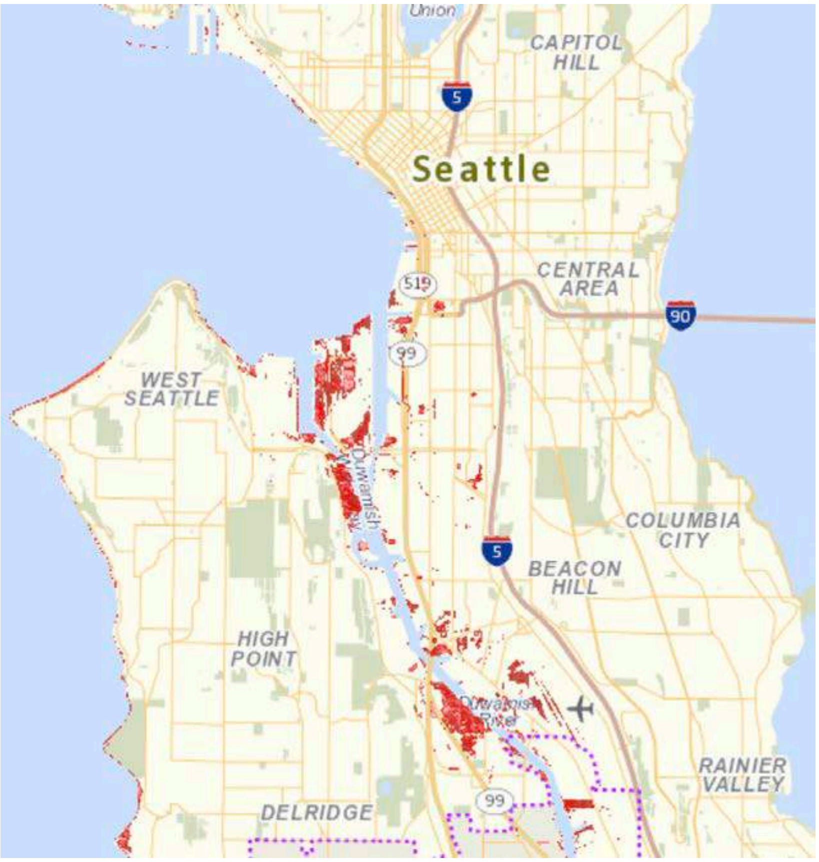


Figure CC 5: Rising sea levels and changing inundation risks in the City of Seattle.

Areas of Seattle projected by Seattle Public Utilities to be below sea level during high tide (mean higher high water) and therefore at risk of inundation are shaded in blue under three levels of sea level rise (Mote et al. 2008) assuming no adaptation (P. Fleming and J. Rufo-Hill, Seattle Public Utilities, pers. comm.). High (50 in [127 cm]) and medium (13 in [33 cm]) levels are within the range projected for the Northwest by 2100; the highest level incorporates the compounding effect of storm surge. Unconnected inland areas shown to be below sea level may not be inundated, but could experience localized flooding due to areas of standing water caused by a rise in the water table and drainage pipes backed up with sea water. Source: http://www.seattle.gov/util/EnvironmentConservation/ClimateChangeProgram/ProjectedChanges/Sea-LevelRiseMap/index.htm

Impact on Forest Ecosystems and Wildfires

Climate change is likely to significantly affect the distribution, growth, and function of forests. Tree growth responses to future climate change will vary both within the region and in time with climate variability, but some locations are likely to experience higher growth (e.g., higher elevations) while other areas are likely to experience reduced growth (e.g., the lower elevation eastern parts of the Cascade Range).

Forests limited by water availability will likely experience longer, more severe water-limitation under projected warming, and reduced warm-season precipitation, resulting in decreased tree growth. Forests limited by energy or temperature will likely experience increased growth, depending on water availability. Expansion of new and current invasive species, both native (e.g., western juniper) and non-native (e.g., yellow starthistle), will influence the response of grassland and shrubland systems to climate change.

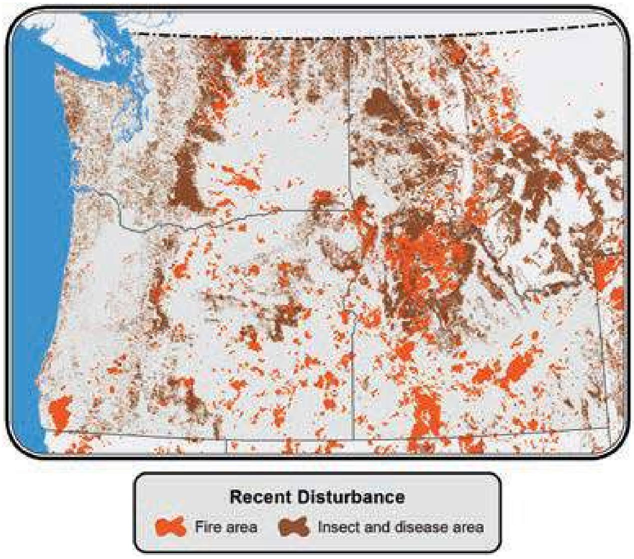


Figure CC 6: Areas of recent fire and insect disturbance in the Northwest

(Source: Climate Change in the Northwest, Bethel et al. 2013)

While it is uncertain what degree climate change will influence high-intensity, stand-replacing fires, it is expected that any increases in future fire activity will threaten fire intolerant shrubs and the greater sage-grouse that depend on them for feeding, nesting, and protection (McKenzie et al. 2004). Several climate change assessment models predict that fire activity in the Northwest will increase in the future in response to warmer and drier summers that reduce the moisture of existing fuels and facilitate fire. One study estimated that the regional area burned per year will increase by roughly 900 square miles by the 2040s (Rogers et al 2011). The future carbon budget of Washington forests will likely be a balance between competing processes. Such processes include increased spring precipitation and CO2 fertilization versus summer drought and intensified fire regimes, all of which will be influenced by changing climatic conditions. Because of the high diversity in the region, different ecoregions within the state may respond in contrasting ways to these interacting factors.

Overall Impacts

Projected regional warming and sea level rise are expected to bring new challenges to the Northwest. Many challenges will be different from those for which regional infrastructure and natural resources policies were intended, and those recently experienced by regional ecosystems. The resultant altered patterns of water supply and demand would challenge northwest water resources management, agriculture, and ecosystems from fish to forests.

Coastal habitat and ecosystems, infrastructure, and communities are expected to experience ongoing reshaping of the physical and ecological environment caused by climate changes on both land and sea. The combined risk of fires, insects, and diseases could cause significant forest mortality and long-term transformation of NW forest landscapes.

The agricultural sector is expected to experience mixed impacts, with some sectors and locations benefiting from projected changes, others sustaining losses, and new opportunities arising. While the projected human health impact of climate change is low for the Northwest, relative to other parts of the United States, key climate-related risks facing our region include extreme heat waves, changes in infectious disease epidemiology, river flooding, and wildfires.

Climate change will have complex and profound effects on the lands, resources, and economies of Northwest tribes, and on tribal homelands, traditions, and cultural practices that have relied on native plant and animal species. Although many of these changes may initially be obscured in the near term by natural variations in climate, they will become increasingly apparent over time, especially those driven by regional warming. Table below provides examples of possible projected changes in extreme climate phenomena and possible impacts.

Projected Impacts of Climate Change in Twenty first Century

Projected changes during the 21st century	Examples of projected impacts
Higher maximum temperatures; more hot days and heatwaves over nearly all land areas (very likely)	• Increased incidence of death and serious illness in older age groups and urban poor • Increased heat stress in livestock and wildlife • Shift in tourist destinations • Increased risk of damage to crops • Increased electric cooling demand and reduced energy supply reliability
Higher (increasing) minimum temperatures; fewer cold days, frost days and cold waves across nearly all land areas (very likely)	• Decreased cold-related human morbidity and mortality • Decreased risk of damage to crops, and increased risk to others • Extended range and activity of some pest and disease vectors • Reduced demand for heating energy
More intense precipitation events (very likely in many areas)	• Increased flood, landslide, avalanche and mudslide damage • Increased soil erosion • Increased flood runoff could increase recharge of some floodplain aquifers • Increased pressure on government and private flood insurance systems and disaster relief
Increased summer drying over most mid-latitude continental interiors and associated risk of drought (likely)	• Decreased crop yields • Increased damage to building foundations caused by ground shrinkage • Decreased water resource quantity and quality • Increased risk of forest fire
Intensified droughts and floods associated with El Niño events in many different regions (likely)	• Decreased agricultural and rangeland productivity in drought- and flood-prone regions • Decreased hydro-power potential in drought-prone regions

Note: The descriptions of likelihood refer to the collective confidence of the IPCC authors in the validity of a conclusion based on observational evidence, modelling results and theory: virtually certain (greater than 99 percent chance); very likely (90–99 percent chance); likely (66–90 percent chance); medium likelihood (33–66 percent chance); unlikely (10–33 percent chance); very unlikely (1–10 percent chance); and exceptionally unlikely (0–1 percent chance) (these likelihood descriptions apply to all results from IPCC Working Group I)
Source: Van Aalst (2006)

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Coastal Hazards Profile

Hazard Description

Coastal Hazards in Washington include both unique coastal manifestations of region-wide hazards like earthquake, tsunami, severe storms and flooding, as well as hazards unique to the coast, including coastal erosion, tidal inundations and climate change-induced sea level rise. Washington's coast includes the 15 counties bordering Puget Sound, the Salish Sea or the Pacific Ocean, including:

- Whatcom
- San Juan
- Skagit
- Island
- Snohomish
- Kitsap
- King
- Pierce
- Thurston
- Mason
- Clallam
- Jefferson
- Grays Harbor
- Pacific
- Wahkiakum

Inundation and loss of property and critical facilities due to erosion and sea level rise are perpetual risks for Washington's coastal communities. Tidal variability, intense wave action and other complex processes, influenced by cycles such as El Niño, have led to rapid loss of beach in several places along Washington's Pacific Coast. According to the National Shoreline Study (1971) conducted by U.S Army Corps of Engineers, while less than 1 percent of state shoreline is threatened by erosion, Washington does have one of the fastest eroding locations along the Pacific Coast at Washaway Beach, present-day North Cove. The images below show the beach shoreline in 1990 and 2011. Red line marks shoreline in 1990.

FIGURE C1: WASHAWAY BEACH SHORELINE CHANGE (SOURCE: USGS VIA GOOGLE MAPS)

Erosion is one of the most visible threats to the coast and has inspired major mitigation and awareness efforts, such as the Grays Harbor Resilience Coalition. Although only the aforementioned 1 percent of Washington's coast is considered threatened by erosion, the threatened areas include multiple communities, including Westport, Ocean Shores and North Cove. The hazard is significant enough that new data collected for Grays Harbor County has made it into the county's updated hazard mitigation plan. One challenge with the erosion hazard is that data on long-term risks and mitigation alternatives does not exist but is needed if coastal communities are to be protected.

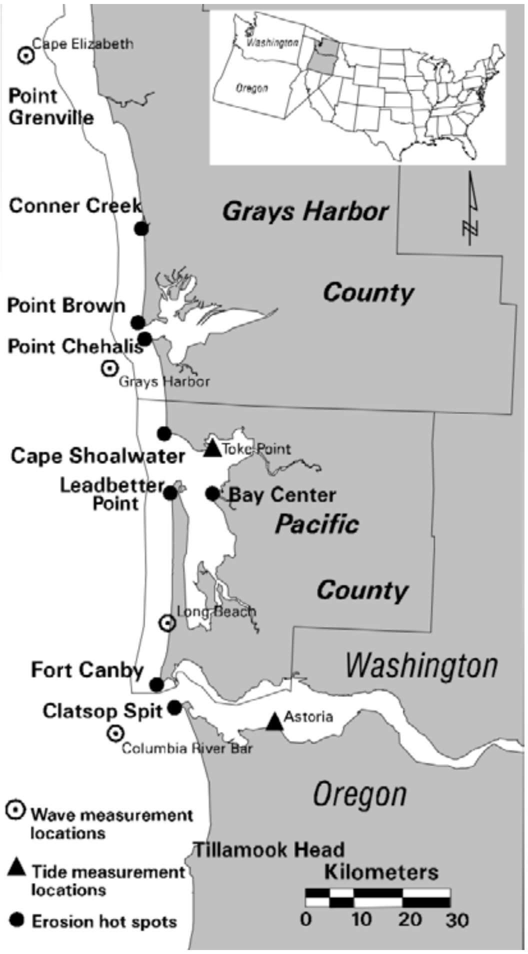

Figure C2: Erosion hotspots in the Columbia River Littoral Cell (Source: Ruggiero et al 1997)

According to a study conducted by Ruggiero and colleagues (1997), a number of the significant erosion hotspots along the Pacific Northwest are located in the Columbia River littoral cell which includes the Grays Harbor and Pacific counties of Washington state.

Intense wave action along the state shoreline is recognized as the key driver of coastal hazards in this region. The wave climate of the Pacific Northwest is known for its severity, with winter storms commonly generating deep-water significant wave heights (SWH) greater than 10 meters.

The study by Ruggiero and colleagues (1997) concluded that annual average of deep-water SWHs and spectral peak periods was about two meters and 10 seconds, respectively; high, long-period waves (averaging about three meters in height and 12 to 13 seconds in period), high water levels, and a west-southwest direction of wave approach are common in the winter months (November through February), whereas small waves (one meter SWHs and eight second periods), low water levels, and wind and waves from the west-northwest are the typical summer (May through August) conditions.

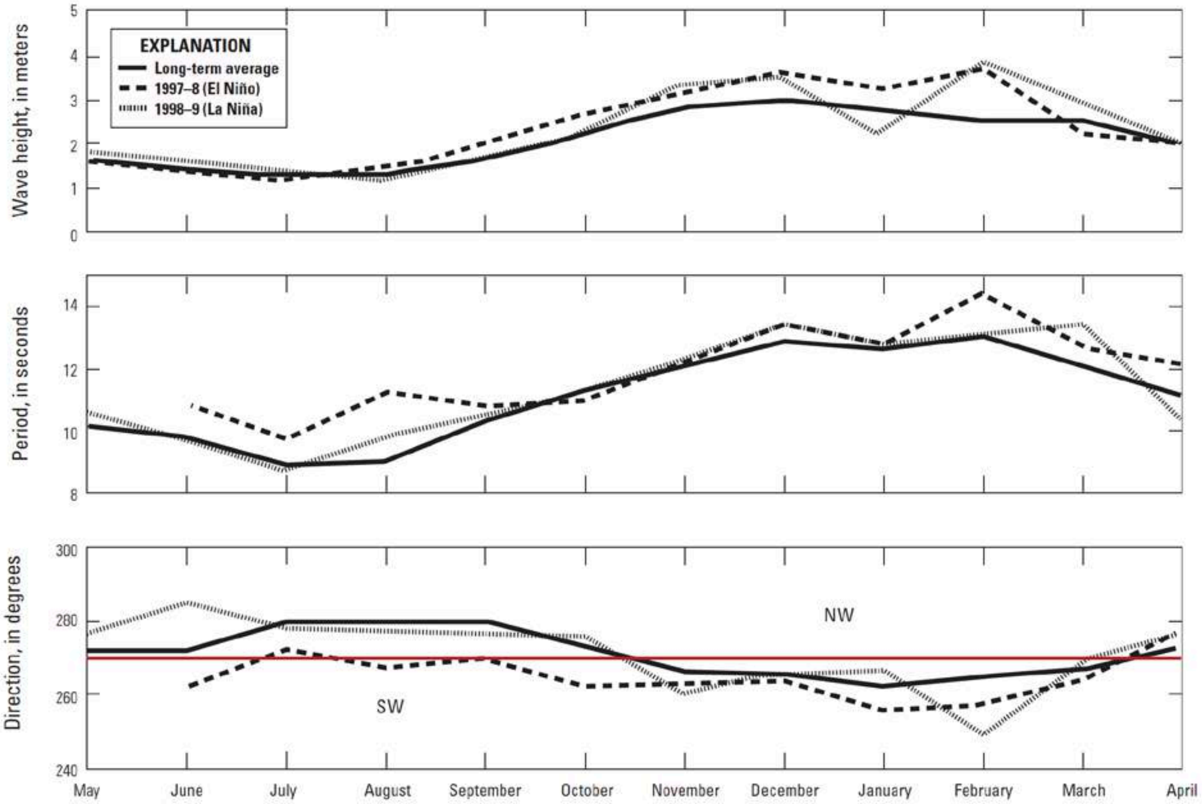

FIGURE C3: MONTHLY MEAN WAVE CHARACTERISTICS (RUGGERIO ET AL, 2013)

The images above show the monthly mean, A, significant wave height, B, period, and C, direction, from the University of California, San Diego Coastal Data Information Program buoy 036 at Grays Harbor, Washington. The solid line represents long-term means beginning in 1981 for wave heights and periods and 1993 for wave direction. Monthly means from the 1997–8 El Niño (dashed line) and 1998–9 La Niña (dash-dot line) are also shown. The red solid line in C represents waves arriving at the coast from due west. NW, northwest; SW, southwest.

The intensity of wave action is closely connected to bluff erosion. Intense wave action results in erosion at the toe of a slope creating unstable bluff profiles, resulting in loss of later slope which may lead to large slabs of bluff failing (Baum 1998). Steepening of the bluff slopes increases the probability of the bluff failures and accelerates the long-term retreat of the bluff. Steeper, unstable bluffs, combined with elevated groundwater levels and/or seismic activity may also result in bluff failures. A major bluff erosion threat are storms with large waves, especially when combined with high tides or elevated sea levels associated with El Niño events (Shipman 2004).

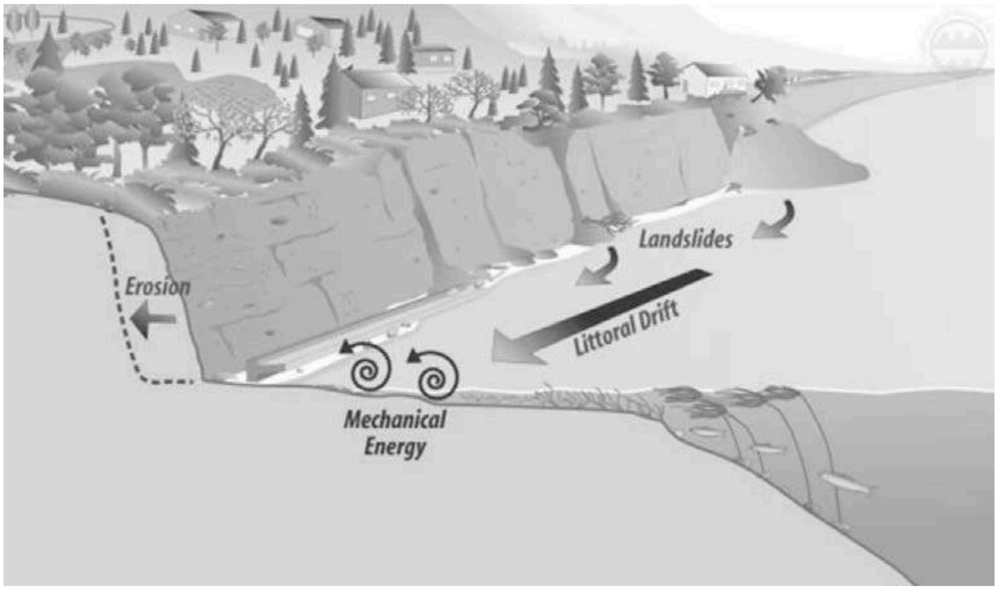

FIGURE C4: BLUFF EROSION PROCESS (SOURCE: WILLIAM ET AL. 2006)

Another related threat to Washington coastal areas is increasing ocean acidification. In a regional study on ocean acidification by NOAA (Feely et al 2012), the researchers found that this region is experiencing increasing ocean acidification at a greater pace and increasing intensity than most other regions around the globe. These changes in ocean chemistry resulting from higher global concentrations of atmospheric CO2, along with regional factors that amplify local acidification, are likely to negatively impact the local marine ecology. Coastal communities dependent on the local marine resources are likely to be exposed to a higher economic risk and will need to adapt to the changing conditions.

Coastal Hazard Location, Extent, and Magnitude

Washington's coastal hazards assessment applies to the 15 counties bordering the Pacific Ocean or Salish Sea, including Puget Sound. These are: Whatcom, San Juan, Skagit, Island, Snohomish, Kitsap, King, Pierce, Thurston, Mason, Jefferson, Clallam, Grays Harbor, Pacific and Wahkiakum. Geographically, the outer (Pacific) coast counties are more rural, with economies based on agriculture, fisheries and tourism. The inner coast counties include the wealthiest and most-populous places in Washington. The manifestation of hazards is also highly local. For example, sea-level rise impacts places different due to isostatic rebound and changes in topography and the wave-action of the outer coast is much stronger than that of the Salish Sea and Puget Sound.

As per the USGS report No. 2012-1007 (Ruggiero et al 2013), much of the shoreline in southwestern Washington prograded rapidly since the 1880s. Therefore, coastal management issues that dealt with accreting and drifting dunes that interrupted views and restricted public access, and coastal erosion hazards, were treated as localized problems with minimal regional implications. However, by the 1990s, the rates of progradation in parts of southwestern Washington had indeed slowed, and the State was faced with a suite of erosion issues. For example, in December 1993 a storm breached a narrow neck of land at the Grays Harbor, Washington South Jetty, and threatened the Westport wastewater treatment plant (Ferber et al 1993). Within just a few years of the jetty breach, Federal, State and local governments invested more than $70 million in coastal stabilization projects within the region, much of it in emergency response to threatened infrastructure. Subsequently, by the mid-1990s, a number of erosion hotspots in places that had previously been accreting were identified in the State (for example, Ocean Shores, Westport, Cape Shoalwater and Cape Disappointment State Park) (Ruggiero et al 2013).

Allan and Komar (2006) have documented increasing wave heights during the past 25 years. They suggest that these trends may be related to global warming and the El Niño Southern Oscillation (ENSO) range that affects both annual wave conditions and monthly mean water levels that raise tidal elevations. In this region, the progressive decadal increase and annual variations in wave conditions is primarily controlled by the North Pacific Index (NPI), the atmospheric pressure difference between the Hawaiian High and Aleutian Low, and the ENSO range (Bacon and Carter 1993). A strong correlation with the multivariate ENSO index (MEI), explains the highest wave conditions occurring during El Niños. Deep-water wave heights, runup levels on beaches and elevated tides result in significantly higher total water levels at the shore during El Niños years, compared with normal or La Niña years (Allan and Komar 2006). These episodic events result in most of the erosion and major property damage from the cumulative effect of coastal hazards along the Washington Coast.

As the population along the coastline continues to grow, population, infrastructure and other development in the coastal areas has increased significantly in the past couple of decades. In response to growing coastal population in previously undeveloped areas along the coast, FEMA has been proactively updating coastal flooding studies under the National Flood Insurance Program (NFIP). Within the official Flood Insurance Rate Map (FIRM) FEMA designates the Special Flood Hazard Area (SFHA) applicable to the community. Within a coastal SFHA are two primary flood hazard zones: Zone VE and Zone AE. Zone VE, also known as a Coastal High Hazard Area, is considered one of the areas of highest risk depicted on FIRMs. Zone VE is designated where wave velocities are expected to be particularly strong and have the potential to cause dramatic structural damage. To address the added wave hazard, more stringent building practices are required in Zone VE, such as elevating a home on pilings so that waves can pass beneath structural supports, and prohibiting buildings elevated on fill, which can be easily washed away by waves. These practices are intended to improve the chance of a home safely weathering a storm.

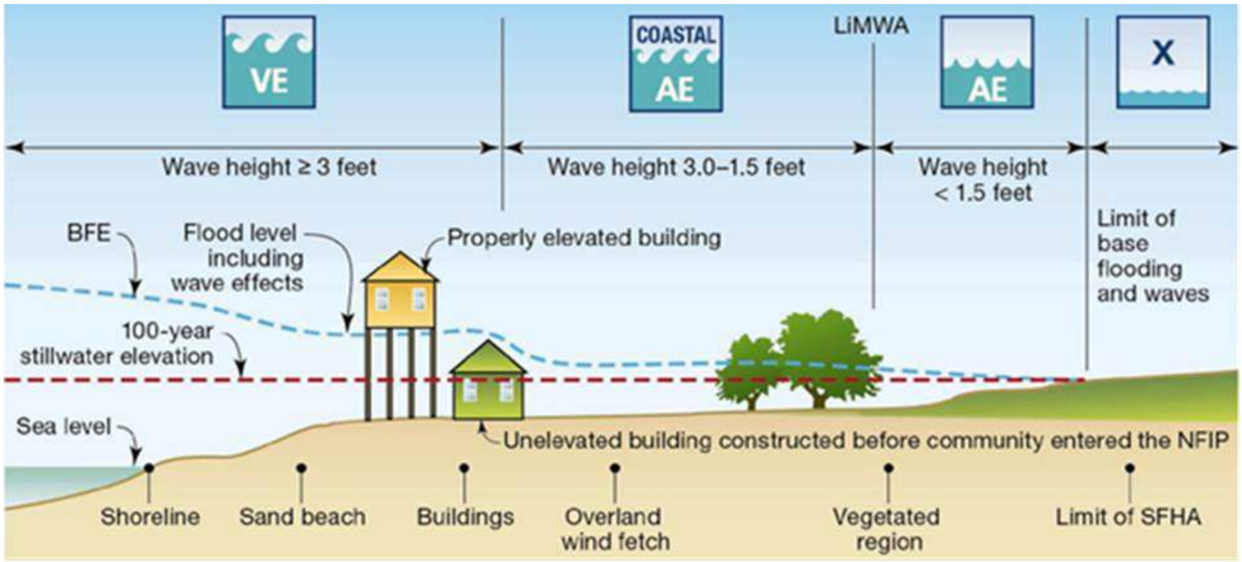

FIGURE C5: COASTAL SFHA (SOURCE: WWW.FEMA.GOV)

With respect to sea level rise trends in the Pacific Northwest region, the researchers have observed significant departures from the global mean rate of increase in sea level (University of Colorado 2012; Nerem et al. 2010; National Research Council [NRC] 2012).

Sea-Level Rise

Sea-level rise (SLR) poses a chronic threat to the coastal communities as a significant proportion of the population in these communities live in low-lying areas along the shore. In addition to inundating low-lying coastal areas, rising sea level will increase coastal flooding caused by storm surges, tsunamis and extreme astronomic tides. Likewise, episodic storm surges of a given height will likely experience shortened recurrence intervals. Over the last century, sea level rose at many locations along the shorelines of Puget Sound. Rates vary, however, as local land motion, weather patterns and ocean currents can amplify or mask regional trends in sea level. Sea levels are projected to rise over the coming century, with a wide range of possible future amounts depending on the rate of global greenhouse gas emissions. Increases in sea level will amplify rise of coastal flooding. (State of Knowledge: Climate Change in Puget Sound, Climate Impacts Group, University of Washington, 2015)

Straus et al, in their national study of topographical vulnerability to sea level rise, determined that the coastal areas of Washington include 97,000 acres of land within 1.0-meter (3.3-feet) elevation of high tide, with almost 75 percent of this being dry land area (area without any wetlands). However, increasing sea level rise will result in increasing wet areas, especially in the low-lying margins of the coastal zones. In addition to inundating low-lying coastal areas, rising sea level will result in increased coastal flooding caused by storm surges, tsunamis and extreme astronomic tides. As the sea level rises, storms of a given magnitude will reach higher elevations and produce more extensive areas of inundation. Likewise, episodic storm surges of a given height will likely have shorter recurrence intervals. Rising sea levels will result in more frequent exceedance of traditional engineering design thresholds leading to greater occurrences of waves breaking over seawalls, flood waters overtopping levees, and storm surges over-washing and breaching barriers.

Currently sea level rise is largely influenced, locally at least, by tectonic forces, ocean circulation fluctuations, and our cooler water tempering expected future water expansion and accompanying increases in water service elevation. Seas also rise with lower atmospheric pressure, and as the frequency of extreme weather events are increasing, we can expect climate change to bring increases in the frequency of periods with low pressure. Actual increases in the quantity of water being added to the system (i.e. ocean) from melting land ice is, for the short term, having less impact in the Northwest.

Tectonic fluctuation is illustrated in Figure C6 and shows time series of sea level measurements at two NOAA tide gauge locations in Washington (Komar et al. 2011). The departure from global means at each of these locations is because the state of Washington is situated on an active subduction zone which generates forces that lead to non-uniform vertical deformation of the overlying land (Chapman and Melbourne 2009). Additionally, post-glacial isostatic rebound (Yokoyama et al. 2000) is causing our northern coastal areas that were once buried under ice to increase in elevation thereby reducing the net effect sea level rise. The Olympic Peninsula is also rebounding. Olympia, Washington however — being at the most southern end of the last continental glacier — is subsiding, placing it in at a greater threat from rises in sea level.

Seasonal ocean circulation and wind field effects caused by El Niño-Southern Oscillation (ENSO) events, the gravitational effects of Alaska's extensive glaciers, are influencing the deviation of Northwest sea levels from the global mean levels.

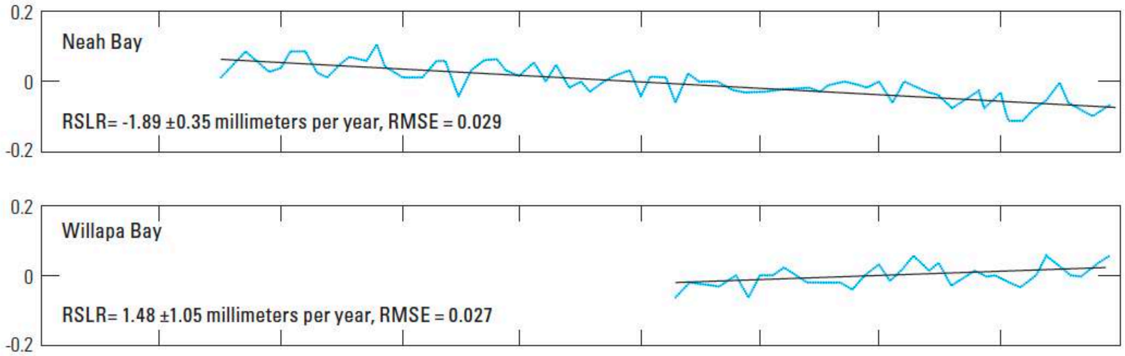

FIGURE C6: TRENDS AND VARIATIONS IN SUMMER SEA LEVELS FOR THE WASHINGTON TIDE GAUGE RECORDS (SOURCE: KOMAR ET AL 2011)

A 2012 assessment of West Coast sea level rise by the National Research Council (NRC 2012) suggests that the upper range of the global contribution to regional sea level rise could be as high as 1.4 meters (55 inches) for Northwest ocean levels in the year 2100. The NRC report also notes that "increases of 3-4 times the current rate [of sea level rise] would be required to realize scenarios of one-meter sea level rise by 2100" (NRC 2012). Figure C7 shows the sea level rise projections for the 21st century (in centimeters and inches) relative to the year 2000. This projection incorporates the global and local effects of warming oceans, melting land ice and vertical land movements along the West Coast (NRC 2012). Although these projections for other latitudes in the Northwest differ by less than an inch, variation in vertical land movement within the region could add or subtract as much as 20 centimeters (eight inches) from the projections for 2100 shown below.

The lower projections assume we, as a global community, can greatly reduce adding additional greenhouses into the atmosphere. The higher projections assume the current rate continues.

However, applying time horizons can be misleading. Seas are rising and there is very little uncertainty that seas will reach 10 feet or even 20 feet above the current sea level assuming the current rate of carbon emissions. The only question is when.

Also, an increase of just one foot will prove significant. People build right up to the edge of what is possible. If a coastal homeowner builds three feet above the mean high tide in most of Puget Sound, that's enough to protect them from a 100-year flood. But if sea level goes up by just a foot, which is almost a foregone conclusion, the resident’s level of protections is not even adequate for a 10-year event. (See City of Olympia: Engineered response to Sea Level Rise, 2010)

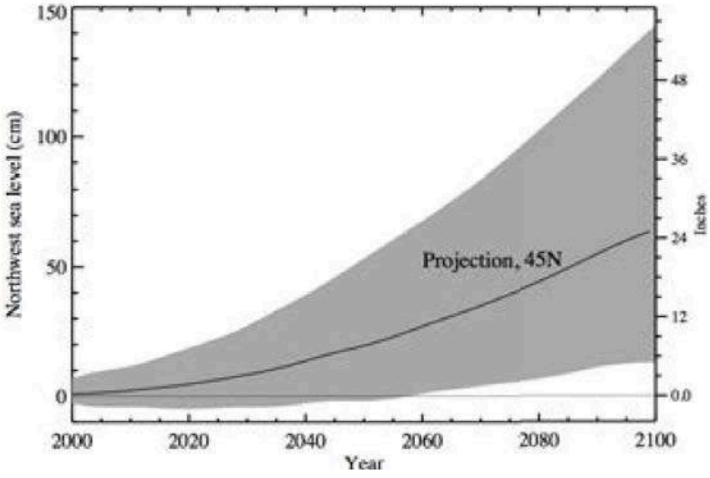

FIGURE C7: PROJECTION FOR RELATIVE SEA LEVEL RISE AT 45 °N LATITUDE, ROUGHLY THE LATITUDE OF LINCOLN CITY AND SALEM, OREGON (SOURCE: NRC 2012)

The shaded area shows a range of projections developed by considering uncertainties in each of those contributing factors, and uncertainties in the global emissions of greenhouse gases.

Tsunamis are another low likelihood high impact threat faced by the coastal communities in Washington state. The counties facing the Pacific Ocean are particularly vulnerable to tsunamis caused by a Cascadia Subduction Zone earthquake. The Tsunami Ready® Program in Washington State includes Clallam, Grays Harbor, Jefferson and Pacific counties. This program also includes nine communities including Aberdeen, Hoquiam, Ilwaco, Long Beach, Ocean Shores, Port Angeles, Raymond, South Bend and Westport. Four Indian Tribes/Nations are also participants and include the Lower Elwha, Makah, Quinault and Shoalwater Bay Tribes. The Tsunami Ready® Program is sponsored by the National Weather Service (NWS) that emphasizes exposure awareness. The program encourages the awareness of tsunami hazards and is not designed to reflect risk.

Tsunamis pose a particular threat for low-lying coastal communities that lack nearby high ground. Such high ground provides a safe gathering area out of the reach of incoming tsunami waves. Modeling has shown that a Cascadia Subduction Zone earthquake could generate a 30-foot high wave. Because the fault is relatively close to land, evacuation times would be limited to 15-30 minutes along our most Western coasts. As a result, at least 13 communities along Washington state's Pacific coastline would be extremely vulnerable to significant loss of life due to the lack of reachable high ground for evacuation. The Ocean Shores and Long Beach peninsulas will likely be transformed into coastal marshes following a tsunami that is generated by a Cascadia Subduction Zone fault rupture. Tsunami hazard has been addressed in detail in the tsunami section of this report.

Past Occurrence and Future Likelihood

While many Washington's coastal communities have continued to witness impacts due to increased inundation and subsidence, and others are experiencing uplift, no detailed database of these events is available. However, there are some specific examples documented by coastal communities with help from state agencies and other stakeholders.

Bainbridge Island: The uplifted beach terraces on the southern third of the island, and most of the bays and coves are highly susceptible to erosion (City of Bainbridge Island 2007). Houses situated on a small strip of beach with water on two sides, such as in Point Monroe, are especially at risk. Other homes along the coastal shoreline built on fill material are at greater risk from coastal erosion and inundation.

Southwest Coastal Washington: Researchers have identified a number of erosion "hot spots" in this region. These are located at the south end of Ocean Shores; near the southern jetty at the Grays Harbor entrance north of Westport; at the north end of the Long Beach peninsula (Leadbetter Point); and just north of the Columbia River entrance near Fort Canby (Kaminsky and Gelfenbaum 1999). The highest erosion rates along the Pacific Coast have been recorded at the north entrance of Willapa Bay (formerly known as Shoalwater Bay), locally referred to as Washaway Beach (Daniels et al. 1998). The same study estimates that since the 1880s, the shoreline has been losing 19.7 meters (65 feet) of beach a year on average. The study also indicates observation of high erosion rates at Ocean Shores, just north of Cape Leadbetter. Researchers also suspect that higher storm waves are reaching the southwest Washington coast due to a northward shift in the storm track as a consequence of broader global climate changes.

Western Whidbey Island: The erosion rates on Whidbey Island, the most populated island of Island County, is estimated to be 1.2 inches per year, which suggests the loss of one meter of bluff or bank every 33 years (Zelo et al 2000). High waves have been a major cause of increased erosion on Whidbey Island, particularly on the southeastern parts of the island and on large spits on Cultus Bay (Johannessen and MacLennan, 2007). Risk analysis conducted by Barton and Frink (2007) using Zillow suggests that along West Beach Road on northwest Whidbey Island approximately $32 million worth of property could be at risk due to increased bluff erosion and landslides with increasing SLR.

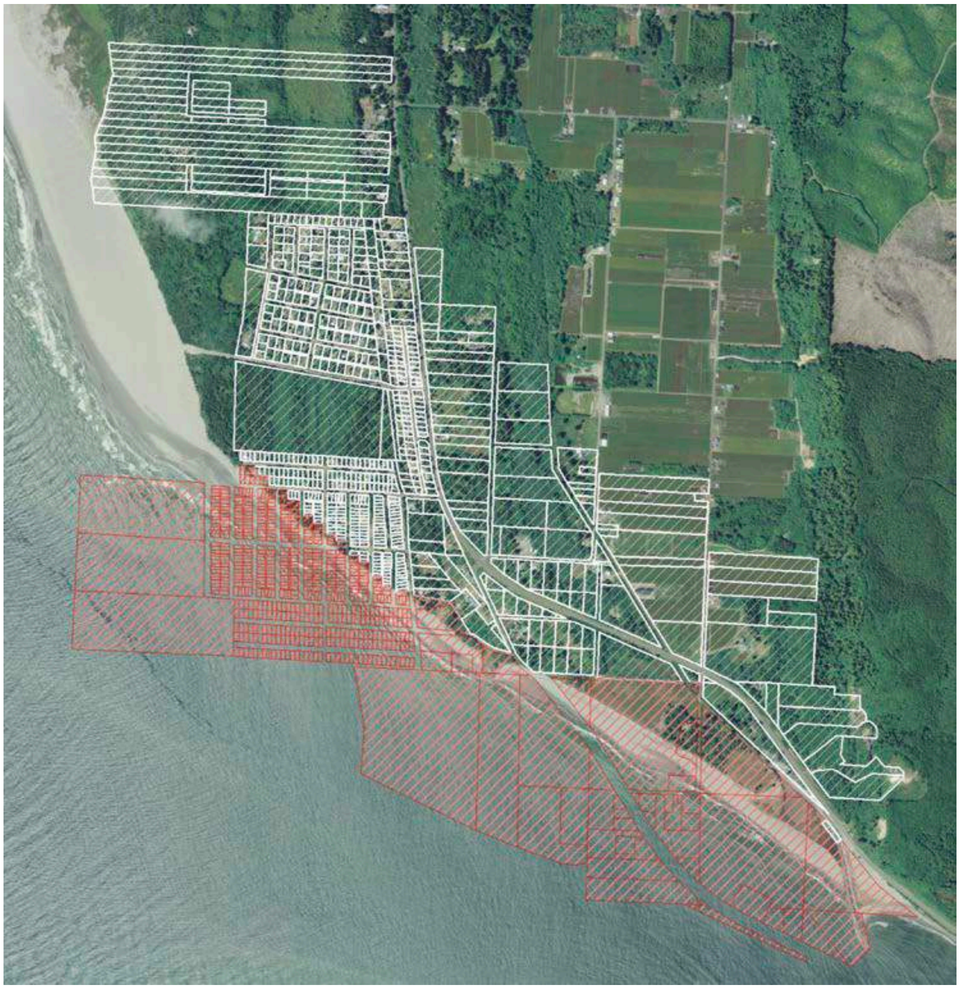

FIGURE C8: MAP OF PARCELS INDICATING AT LEAST 50% LOSS OF LAND MASS TO SHORELINE EROSION AS OF MAY 2015 (SOURCE: TALEBI ET AL 2017)

North Cove: As per Talebi et al (2017) this area in Pacific County experiences the most rapid rates of erosion on the US Pacific Coast – averaging roughly 100 feet per year for the last century; erosion has destroyed about 3,000 acres of public and private lands and recreational beaches, including 30 homes, businesses, a grange hall, a public schoolhouse, a Coast Guard station and has twice forced relocation of the Coast Guard Lighthouse (as quoted in the report based on 1970 data); a national wildlife refuge was lost in the 1990s, and as of May 2015, approximately 640 of the original 766 parcels within the Blue Pacific Shores and Seamobile subdivisions have been lost to the eroding shoreline at Washaway Beach (figure C8).

SHELDUS database provides a limited database of coastal flooding events recorded between 1960-2017 in the coastal counties of Washington. As per the online database, 100 coastal flooding events were recorded in the Washington coastal counties during this period. These events resulted in estimated property damages worth $4.9 million. Most coastal flooding events occurred in Pacific County (12) followed by Grays Harbor (11).

Coastal Flooding Events (1960 2017)		
County	Number of Events	Total Property Damage (Adjusted to 2016)
Asotin	0	0
Benton	0	0

Coastal Flooding Events (1960 2017)

County	Number of Events	Total Property Damage (Adjusted to 2016)
Chelan	0	0
Clallam	6	143,013
Clark	3	125,353
Columbia	0	0
Cowlitz	3	$125,353
Douglas	0	0
Ferry	0	0
Franklin	0	0
Garfield	0	0
Grant	0	0
Grays Harbor	11	$475,647
Island	1	$36,088
Jefferson	6	$295,900
King	4	$401,297
Kitsap	6	$490,562
Kittitas	0	0
Klickitat	0	0
Lewis	5	$450,236
Lincoln	0	0
Mason	5	$450,236
Okanogan	0	0
Pacific	12	$462,675
Pend Oreille	0	0
Pierce	4	$401,297
San Juan	2	$53,164
Skagit	2	$53,164
Skamania	1	$36,088
Snohomish	5	$418,372
Spokane	0	0
Stevens	0	0
Thurston	3	$129,591
Wahkiakum	9	$133,438
Walla Walla	0	0
Whatcom	3	$225,646
Whitman	0	0
Yakima	0	0
Grand Total	91	$4,907,119

Source: Hazards & Vulnerability Research Institute (2017). The Spatial Hazard Events and Losses Database for the United States, Version 16.0 [Online Database]. Columbia, SC: University of South Carolina. Available from http://www.sheldus.org

Between 1960 and 2017, Washington experienced at least one significant coastal flooding event annually. In 10 of these years, there have been multiple significant coastal flooding events (two or more), and seven times the state experienced five or more coastal flooding events in the same year. Based on this data the likelihood of a major coastal flooding in any given year is 23 percent, and the probability of multiple flooding events (five or more) in any given year is estimated to be 12 percent. It is important to note that these estimates are based on past data on coastal flooding. Future probability of coastal flooding in coastal communities is likely to be significantly higher due to the sea level rise and increases in episodic extreme events and the associated coastal impacts of climate change.

Years with at least One Major Coastal Flooding Event (1960 2017)

Year	Coastal Flooding Event
1972	32
1973	17
1974	11
1967	11
2003	7
2014	6
1977	5
2016	4
2007	2
1992	2
2002	1
2001	1
1997	1
Grand Total	100

Source: Hazards & Vulnerability Research Institute (2017). The Spatial Hazard Events and Losses Database for the United States, Version 16.0 [Online Database]. Columbia, SC: University of South Carolina. Available from http://www.sheldus.org

Coastal risk assessment is not simple due to the variety of the complex natural processes that occur along the coastline. There is no standard methodology, and even the data required to make such predictions are the subject of much scientific debate. A few of the common predictive approaches that have been adopted by researchers (National Research Council, 1990), include: 1) extrapolation of historical data (e.g., coastal erosion rates), 2) static inundation modeling, 3) application of a simple geometric model (e.g., the Bruun Rule), 4) application of a sediment dynamics/budget model, or 5) Monte Carlo (probabilistic) simulation based on parameterized physical forcing variables. Each of these approaches, however, has its shortcomings or have limited validity for specific applications (National Research Council, 1990). Furthermore, coastal hazard mitigation measures in the form of beach nourishment, construction of seawalls, groins, and jetties, as well as coastal development itself, dictated by federal, state and local priorities for coastal management may have a significant effect of risk relocation along the shoreline.

Relationship to other Hazards

Coastal hazards associated with erosion, and sea level rise directly impact the communities along the Washington Coast and the infrastructure within the low lying coastal zones. Changing climatic conditions will greatly increase the future risks associated with coastal hazards. While not all communities will experience the same impacts, it is highly likely that most coastal communities will face greater risks from coastal hazards in the coming decades. The potential impacts will vary among the coastal communities based on local variations in projected drivers (e.g., sea level rise, landslide and erosion risk, evolving floodplains), local coastal topography, and compounding effects of multiple climate impacts (e.g., sea level rise, coastal flooding, landslides).

Coastal residents and infrastructure facilities in low-elevation coastal areas are at greatest risk from coastal hazards. About 323 sq. miles of area in Washington state is subject to 100-year coastal flooding (1 percent annual chance) with a resident population of 78,000 in 2000 (Crowell et al 2010). Many important roadways in coastal counties run along rivers or creeks and may experience increasing damage from river flooding, debris flows, bridge scouring and/or landslides. Approximately 4,500 km (2,800 mi) of roads in the coastal counties of Washington and Oregon are in the 100-year flood plain (Douglass and Krolak 2008).

Sea level risk will also exacerbate coastal river flooding. Higher sea levels can increase the extent, depth and duration of flooding by making it harder for flood waters in rivers and streams to drain to Puget Sound. (State of Knowledge: Climate Change in Puget Sound, Climate Impacts Group, University of Washington, 2015)

Coastal hazards are also likely to be impacted by changing sediment transport regimes due to both changing river flows and receding glaciers. These changes are projected to alter the shape and depth of river channels resulting in increasing risk of flooding downstream in the coastal communities.

Coastal impacts from climate change have the potential to significantly impact the economies of coastal communities and a number of regionally important sectors over the long term. These risks stem primarily from the region’s extensive seaport and coastal infrastructure, and limited options for alternative transportation corridors along coastal locations. Coastal hazard events will also likely impact local marine populations. Changes in distribution, abundance, and productivity of marine populations due to coastal changes and changing ocean conditions will impact the level and composition of landings and the value of landings in Washington commercial fisheries (Dalton and Mote 2013).

Coastal Risk Assessment and Mitigation

Due to the composite nature of coastal hazards, and severe limitations in data quality and availability, a separate risk index did not produce a meaningful assessment of overall coastal vulnerability using our methodology. There is not a comprehensive understanding of erosion risk in Washington because there hasn't been the investment needed to collect the data and analysis to accurately determine risk. Given the capacity and resources at the state and local level, erosion/shoreline change data and analysis has been site specific – collected in areas of highest concern or places facing existing loss (i.e., North Cove, Westport, Ocean Shores, etc.). The Grays Harbor Hazard Erosion Hazard Profile in their updated Hazard Mitigation Plan is an example of the kind of risk assessment required.

Mitigation measures for coastal erosion and sea-level rise are especially challenging because often the most viable long-term measure is retreat or relocation away from beaches. In some communities, such as Long Beach, this is practically impossible. The measures intended to reduce risk to these communities include beach nourishment, especially using sediment from USACE dredging projects. Another measure to reduce erosion, shoreline armoring, has temporary and limited effectiveness and has multiple negative impacts on shoreline habitats. For example, the Puget Sound Partnership Action Agenda includes a strategy to reduce shoreline armoring as part of restoring Puget Sound. Armoring also has unpredictable impacts on nearby unarmored shorelines and, being inherently temporary, can project a false sense of security about the long-term viability of shoreline properties.

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Dam Failure Hazard Profile

Risk Summary

Frequency – There is a dam failure in Washington once every three years.

People – Depending on the location of the dam, failure of these types of structures could affect zero to thousands of people depending on the population located downstream.

Property – Property can be dramatically affected in the event of a dam failure. If a failure occurs above a highly developed area, damages could reach $500 million dollars.

Economy – The economy of Washington could be affected by a dam failure due to loss of homes, businesses and infrastructure such as transportation corridors and irrigation facilities, thus lowering the overall tax base for the affected area.

Environment – Although the environment can be severely affected by a dam failure due to the flood that results from this type of incident, the likelihood that such an incident will eradicate 10 percent of a single species or habitat is considered unlikely and thus does not meet this category's minimum threshold.

State operations and facilities – Many dams are owned by state agencies such as the Department of Natural Resources (DNR) and Department of Fish and Wildlife. These dams are often in more remote areas and are more vulnerable to hazards that can lead to dam failure such as wildfire and debris flows.

First responders – Risks to first responders are low.

Public confidence – In general, there is little awareness of dam failure hazards. The near-failure of the Howard Hansen dam on the Green River was a rare exception. It led to a massive increase in flood insurance policies until it was successfully repaired. In Washington, homeowners are not alerted to potential dam safety issues when they build in a dam inundation area, although dam owners are moved into higher risk categories with more regulation when this occurs.

Hazard assessment – A dam failure may create a hazard to the areas upstream and downstream of the dam. The downstream impact of a dam failure is a catastrophic flood event harming people, property and the environment. The upstream impact could include the loss of a drinking water supply, irrigation water, recreational opportunities, commercial endeavors, property values and water for hydropower generation.

Previous occurrences – Since 1918, the Washington State Department of Ecology reports 19 dam failures resulting in a total of nine lost lives. A complete list of dam incidents and failures is provided in Table 2.

Probability of future events – Since 1970, there has been, on average, a dam failure about every three years. Washington state provides laws, regulations, written guidance, periodic inspections and technical assistance to help reduce the probability of dam failures.

Jurisdictions at greatest risk – Jurisdictions at greatest risk are those with the most development downstream from high hazard dams and those which rely the most on the impounded water for essential services like drinking water or irrigation supply. With the state population increasing every year, homes and other infrastructure are frequently being constructed downstream from dams. Dams originally rated as low hazard were not designed to the more stringent requirements of high and significant hazard dams.

Dams located in the Cascadia Subduction Zone of Western Washington may be more vulnerable especially if the dam is older and not designed to more modern seismic criteria.

While the failure of dams with a high hazard potential for loss of life are remote, the number of failures of low-hazard dams are more likely to occur. The Department of Ecology's Dam Safety Office (DSO) only examines low-hazard dams when contacted by the owner to address a problem or if a complaint has been received. Although theses dams are rated low-hazard, there is still the possibility of undesirable impacts should one of them fail.

There are also dams below the DSO jurisdictional level of 10 acre-feet so they are not monitored or inspected. These dams — especially ones closer in volume to the 10 acre-feet level — could pose a significant risk to downstream people, infrastructure and environment.

With the increased attention to climate change, it is necessary to consider the potential effects this may have on Washington state, including dam management. There is the potential for unusual or more frequent heavy rainfall and flooding in some areas while the potential for drought is predicted in other areas. Increased floods can overwhelm dams and trigger landslides which may alter watercourses tied to a dam. Increased wildfires in drought areas eliminate the vegetation which meters the amount of runoff entering a dam impoundment.

Special note – The intent behind this hazard profile is not to provide an all-encompassing source of information but to increase awareness of the potential impact from this hazard. Therefore, this profile will not attempt to estimate potential losses for any particular dam. This profile will only provide general information on the dams within the state. The Washington State Department of Ecology is the primary source of information and subject matter experts for dam related issues.

Hazard Profile

A dam is defined as an artificial barrier that can impound 10 acre-feet or more of water or water-like substances such as mine tailings, sewage and manure. A dam failure can result in the uncontrolled release of impounded water resulting in downstream flooding, which can affect life, property and the environment. The dam failure could also result in loss of essential services provided by the impounded water such drinking water supply, irrigation water and water for hydropower generation.

Failures can involve the dam itself, or its appurtenant structures such as spillways and piped outlets. Dam failures can be caused by heavy periods of rain, flooding, earthquakes, blockages, landslides, lack of maintenance, improper operation, poor design and construction, vandalism or terrorism.

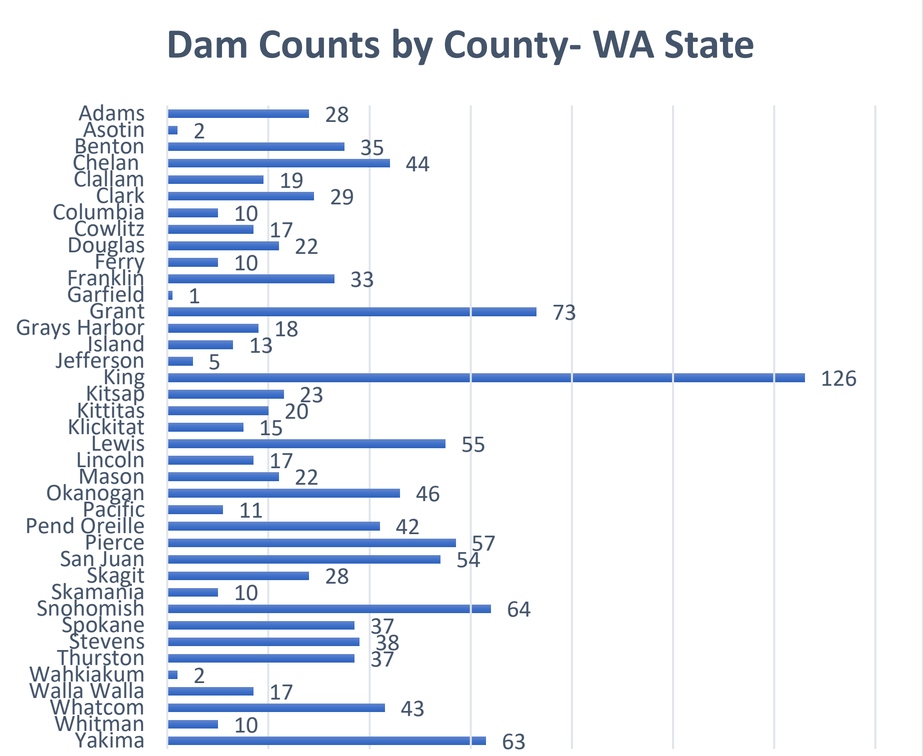


FIGURE D1: DISTRIBUTION OF DAMS BY COUNTY (SOURCE: WA ECY DAM INVENTORY 2017)

Dams in Washington

Overall dam safety in Washington state is managed by the State Department of Ecology's Dam Safety Office (DSO). The DSO's September 2017 Inventory of Dams identifies 1,197 dams of 10 acre-feet or more. A breakdown of dams by county is provided in Figure 1 below.

On a federal level, the number of dams in the United States is maintained by the US Army Corps of Engineers through their National Inventory of Dams (NID). The NID contains information on approximately 90,000 dams throughout the U.S. with information from all 50 states, Puerto Rico and 16 Federal agencies.

In order for a dam to be placed on the NID list, the dam must meet at least one of the following criteria:

- High hazard potential classification - loss of human life is likely if the dam fails
- Significant hazard potential classification - no probable loss of human life but can cause economic loss, environmental damage, disruption of lifeline facilities or impact other concerns
- Equal or exceed 25 feet in height and exceed 15 acre-feet in storage
- Equal or exceed 50 acre-feet storage and exceed 6 feet in height

The 2016 NID for Washington state lists 784 dams. This number differs from Washington state's inventory because there are dams which do not meet one of the four NID criteria above, but do meet the state's 10-acre-foot jurisdictional level.

It should be noted that the Department of Ecology does not regulate levees. Levees are managed by local government and the US Army Corps of Engineers as part of flood control systems.

Age of Dams

The average life expectancy of a dam is about 50 years and over half of Washington's dams are at or beyond that age. See Figure 2. The age of a dam may be a factor in its stability because some materials may deteriorate under continued load and environmental conditions. In addition, as with any technology, there have been enhancements in dam materials, design and construction techniques over the years which earlier projects could not take advantage of. In particular, seismic design for the earthquake potential in the Pacific Northwest has advanced greatly and some older dams may not fare well under the dynamic conditions posed by an earthquake.

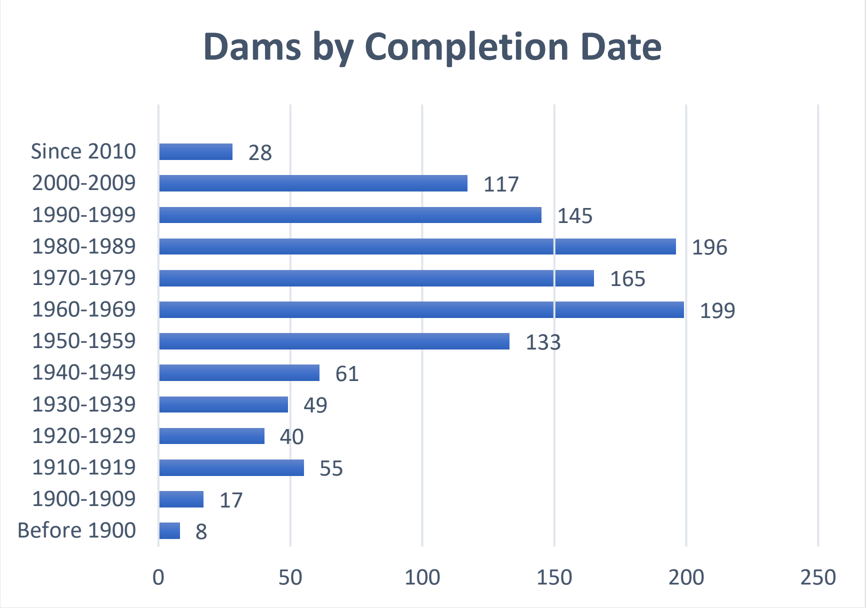


Figure D2: Dams by Completion Date (Source: WA ECY Dam Safety Office Dam Inventory)

Hazard Classification of Dams

All dams are assigned a high, significant or low hazard classification based on potential of loss of life and damage to property and the environment should the dam fail. This classification is considered the Dam Hazard. Classifications can change over the life of a dam based on property development and changing demographics upstream and downstream of the dam. Washington state used the matrix in Table 1 to designate the hazard class of each dam.

Downstream Hazard Classification				
Downstream Hazard Potential	Downstream Hazard Class	Population at Risk	Economic Loss Generic Descriptions	Environmental Damages
Low	3	0	Minimal. No inhabited structures. Limited agriculture development.	No deleterious materials in water.
Significant	2	1 to 6	Appreciable. 1 or 2 inhabited structures. Notable agriculture or work sites.	Limited water quality degradation from reservoir contents.

			Secondary highway and/or rail lines.	and only short-term consequences.
High	1C	7 to 30	Major. 3 to 10 inhabited structures. Low density suburban area with some industry and work sites. Primary highways and rail lines.	Severe water quality degradation potential from reservoir contents and long-term effects on aquatic and human life.
High	1B	31-300	Extreme. 11 to 100 inhabited structures. Medium density suburban or urban area with associated industry, property, and transportation features.	Severe water quality degradation potential from reservoir contents and long-term effects on aquatic and human life.
High	1A	More than 300	Extreme. More than 100 inhabited structures. Highly developed, densely populated suburban or urban area with associated industry, property, transportation and community lifeline features.	Severe water quality degradation potential from reservoir contents and long-term effects on aquatic and human life.

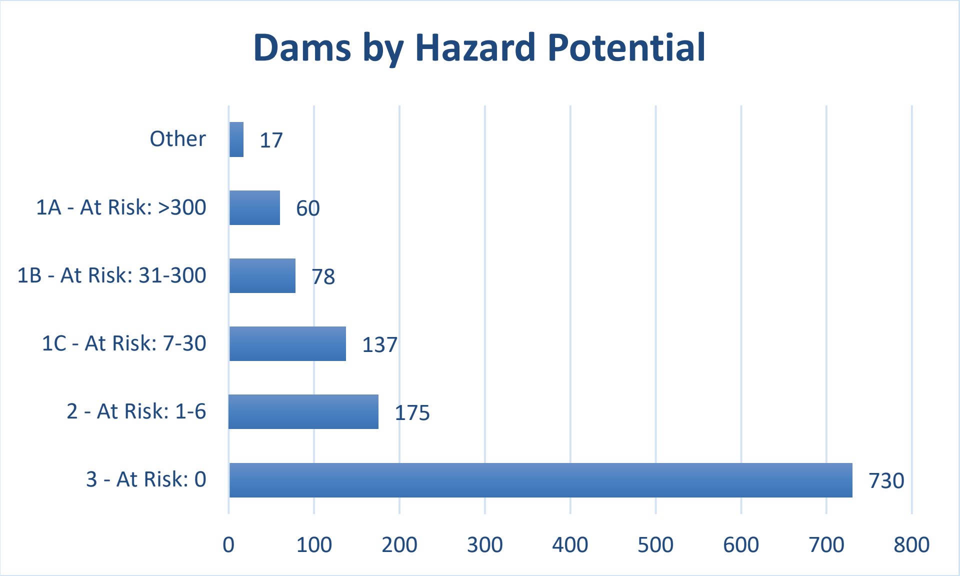


FIGURE D3: DAMS BY HAZARD POTENTIAL IN WASHINGTON STATE (SOURCE: WA ECY DAM INVENTORY 2017)

The DSO assigns a hazard class to each dam as part of the permitting process for new dams or modifications to existing dams. During periodic reviews, the hazard class may be re-assessed if there have been significant changes to the watershed which is captured by the dam or increased development downstream of the dam. State maps showing the approximate locations of high, significant and low hazard dams can be found in Figures 4, 5, and 6 respectively.

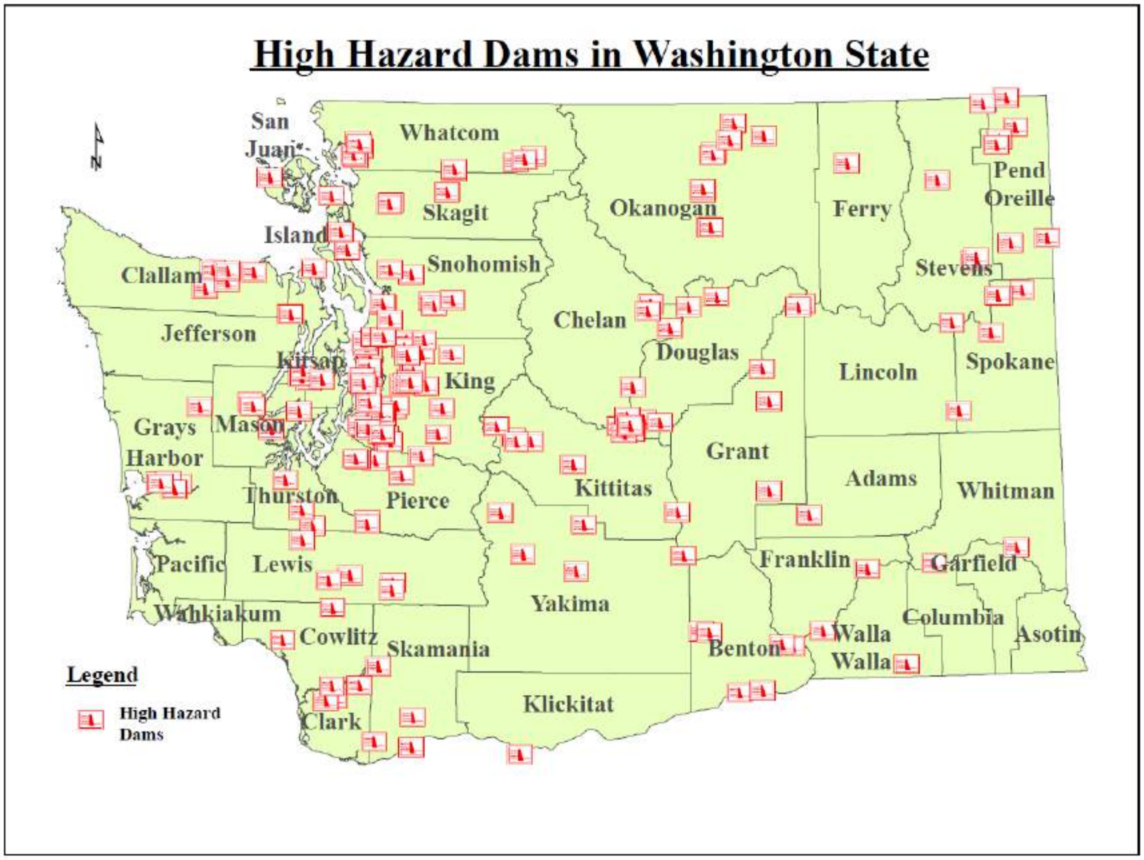


FIGURE D4: HIGH HAZARD DAMS IN WASHINGTON

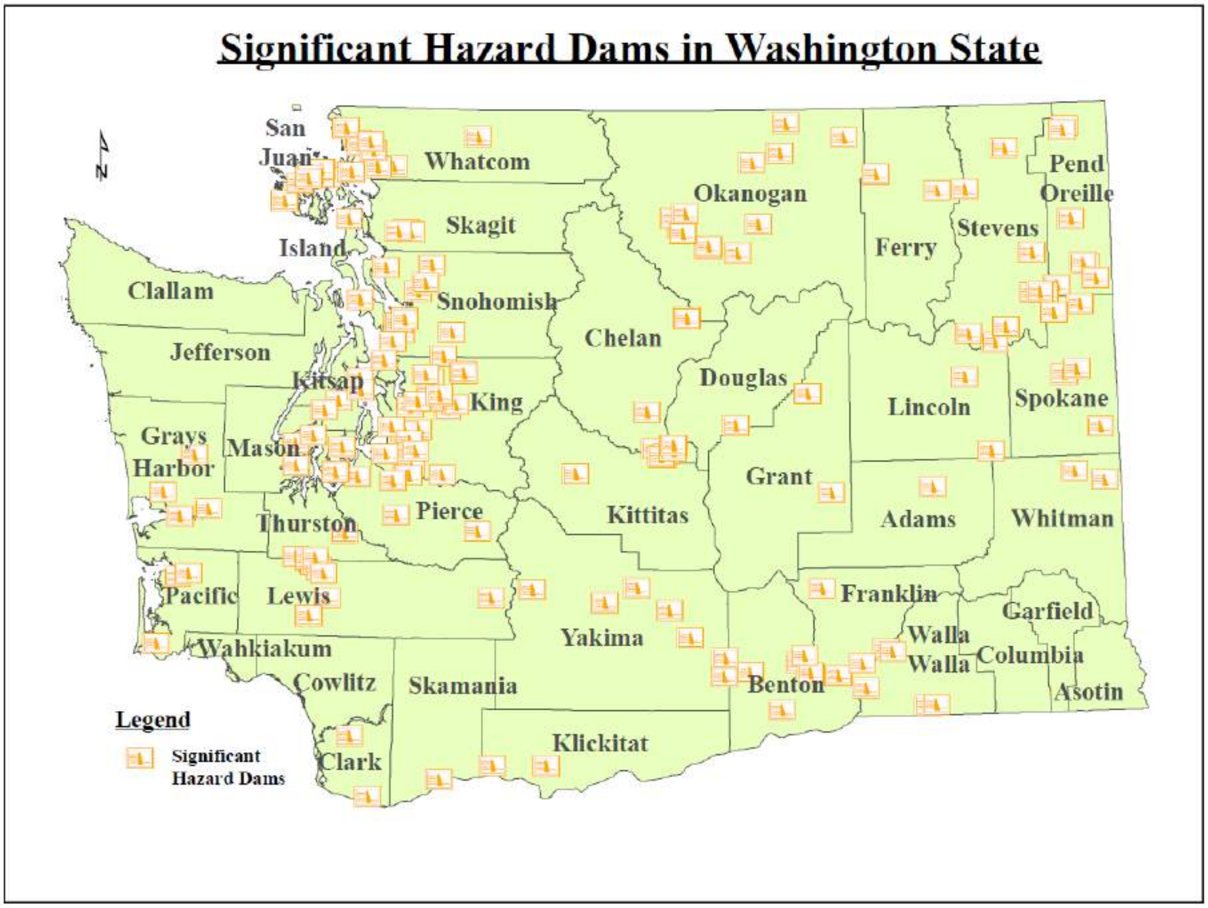


FIGURE D5: SIGNIFICANT HAZARD DAMS IN WASHINGTON

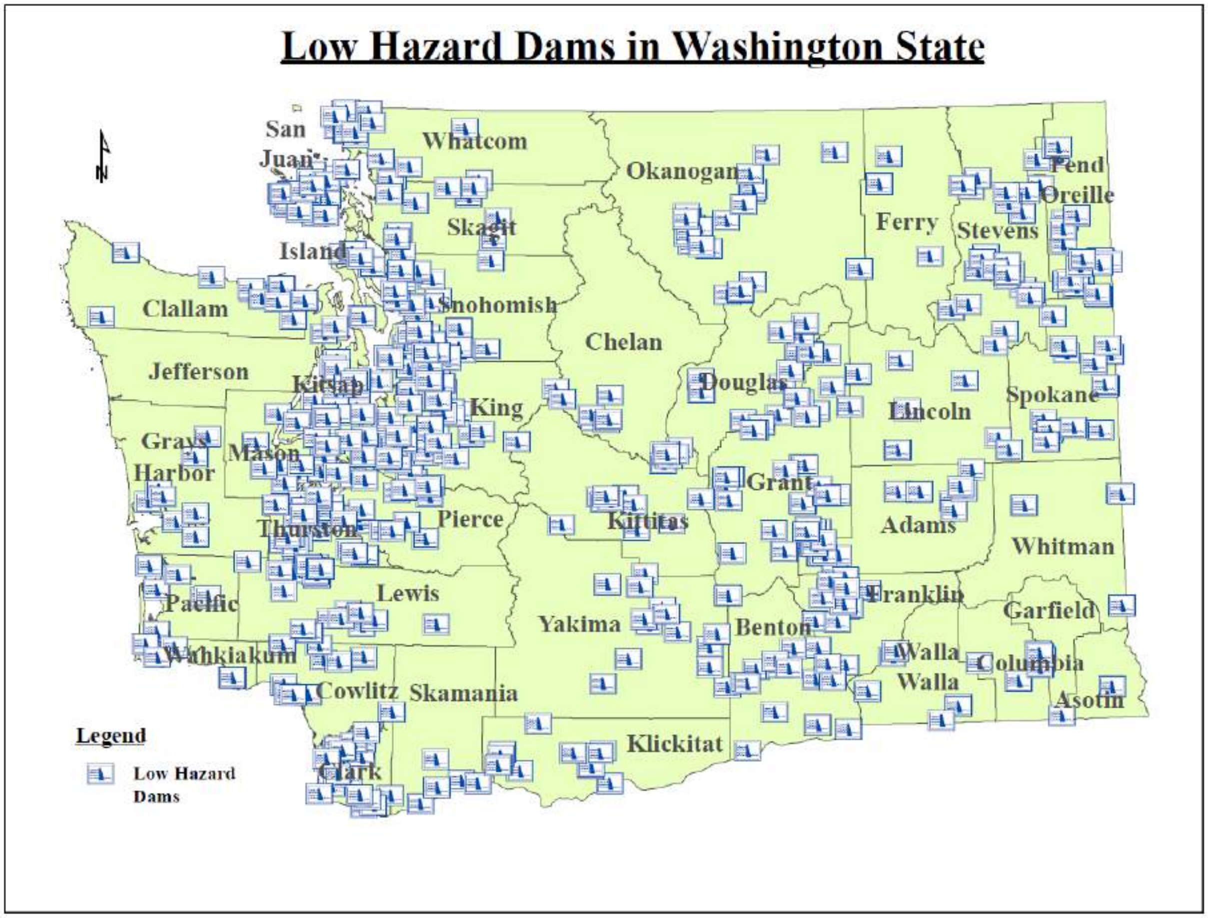


FIGURE D6: LOW HAZARD DAMS IN WASHINGTON

Dam Ownership

Dams are owned by a variety of entities as shown in Figure 6 below. Most dams in Washington are owned by private individuals and businesses. The ownership of a dam could contribute to the safety of a dam

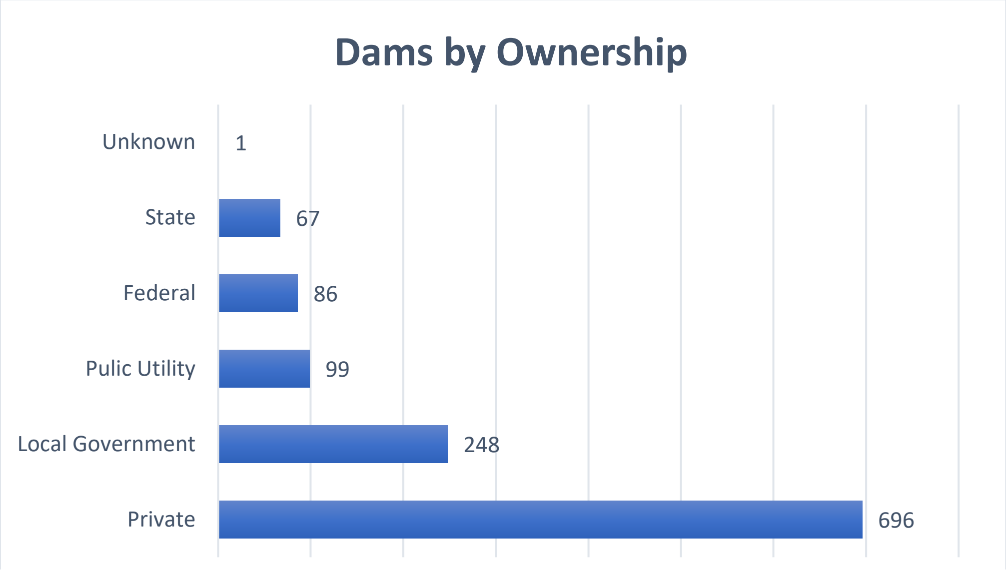
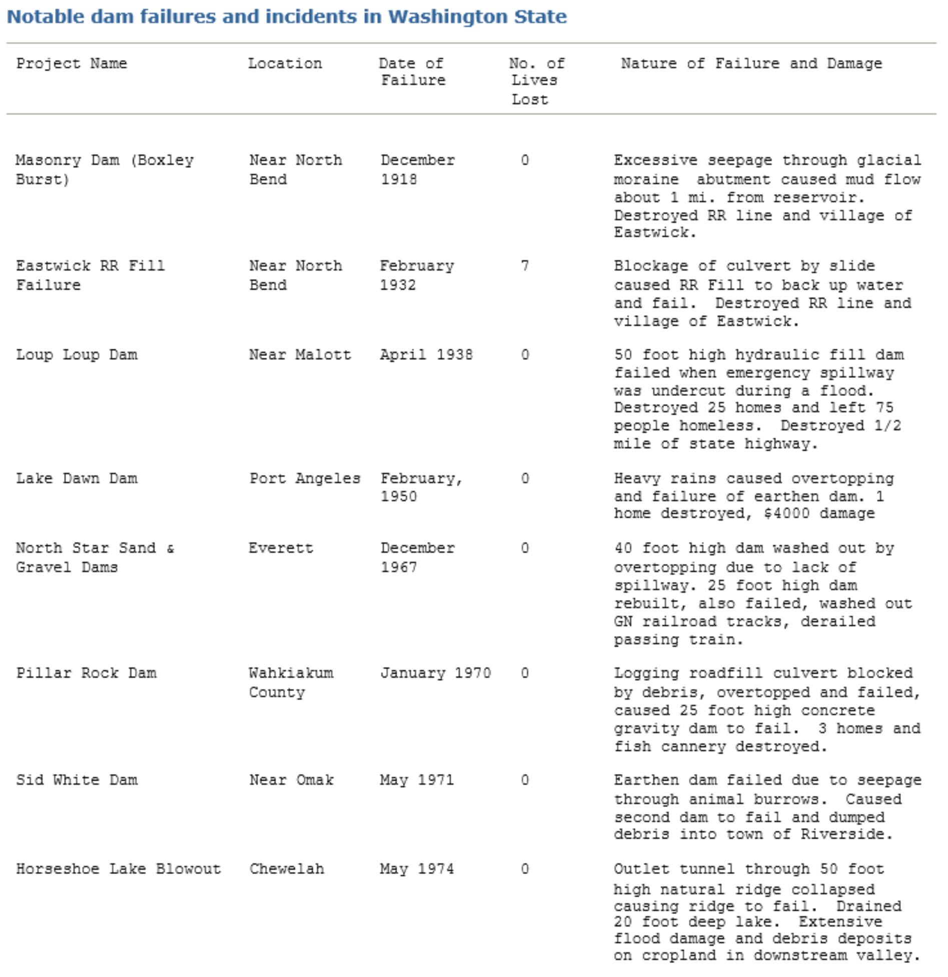


FIGURE D7: DAMS BY OWNERSHIP (SOURCE WA ECY DAM INVENTORY 2017) based on the technical, emergency and funding resources available to the owner. Most federal dams have their own well-developed dam safety offices and provide regulatory oversight to those dams. This includes some of the state's biggest dams such as the hydroelectric dams on the Columbia River. Some privately-owned dams are managed by an individual or small homeowner's association. These entities typically do not have on-site dam engineers or equipment to provide maintenance and operational support. A breakdown of dam ownership in Washington state is found in Figure 7 below.

Previous Occurrences

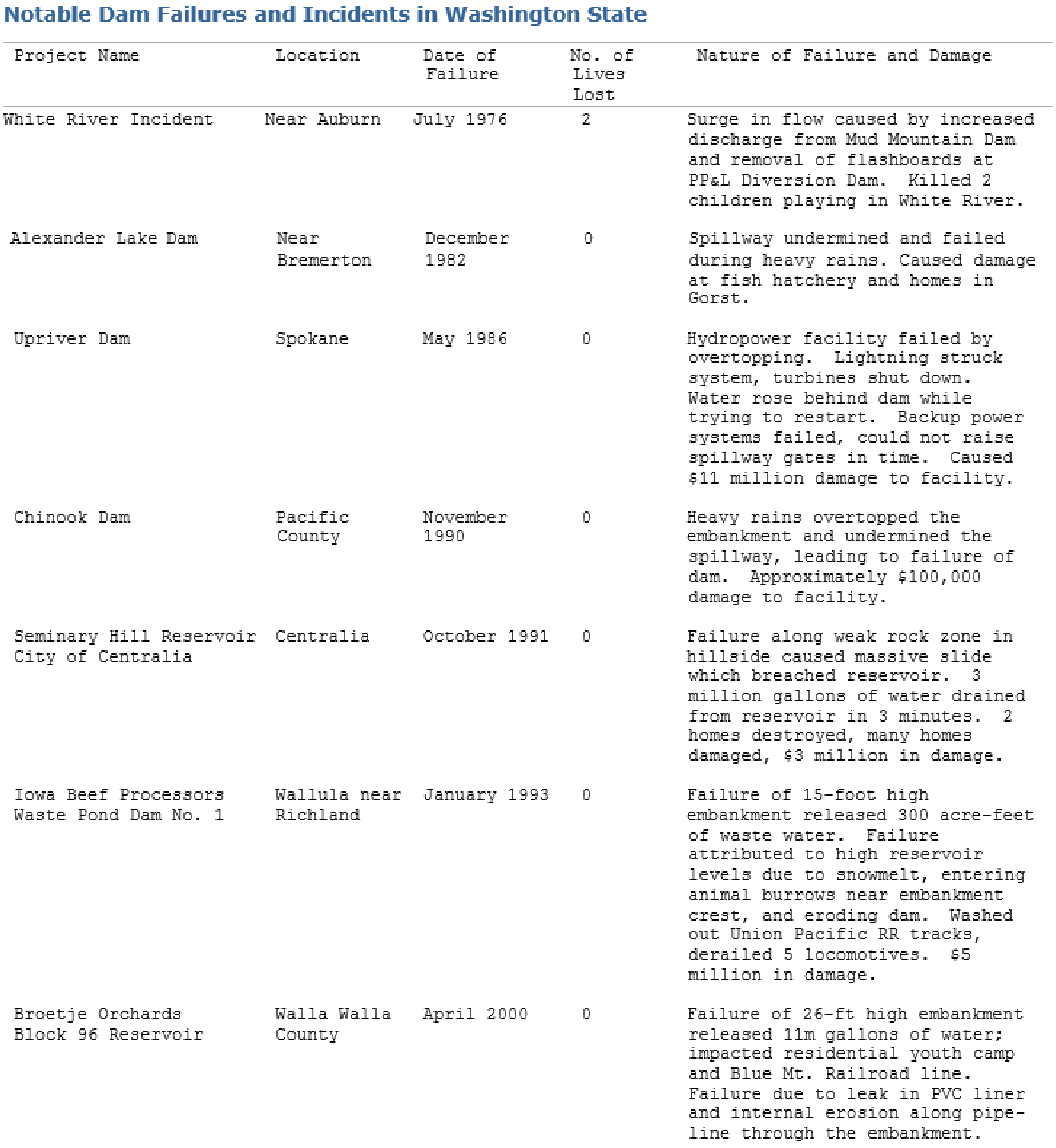
Washington has had 19 notable dam incidents or failures since 1918 (see Table 2). Since 1970, there has been, on average, a dam failure about every three years. The total loss of lives during that time was two people in the 1976 Mud Mountain Dam incident.

In addition to failures, there are numerous events and conditions which occur every year that require actions to prevent failure. Typical scenarios include the identification of a dam condition such as excessive leakage or development of a sinkhole which requires the dam to be operated at less than full capacity while an investigation takes place and repairs are made.



Notable dam failures and incidents in Washington State

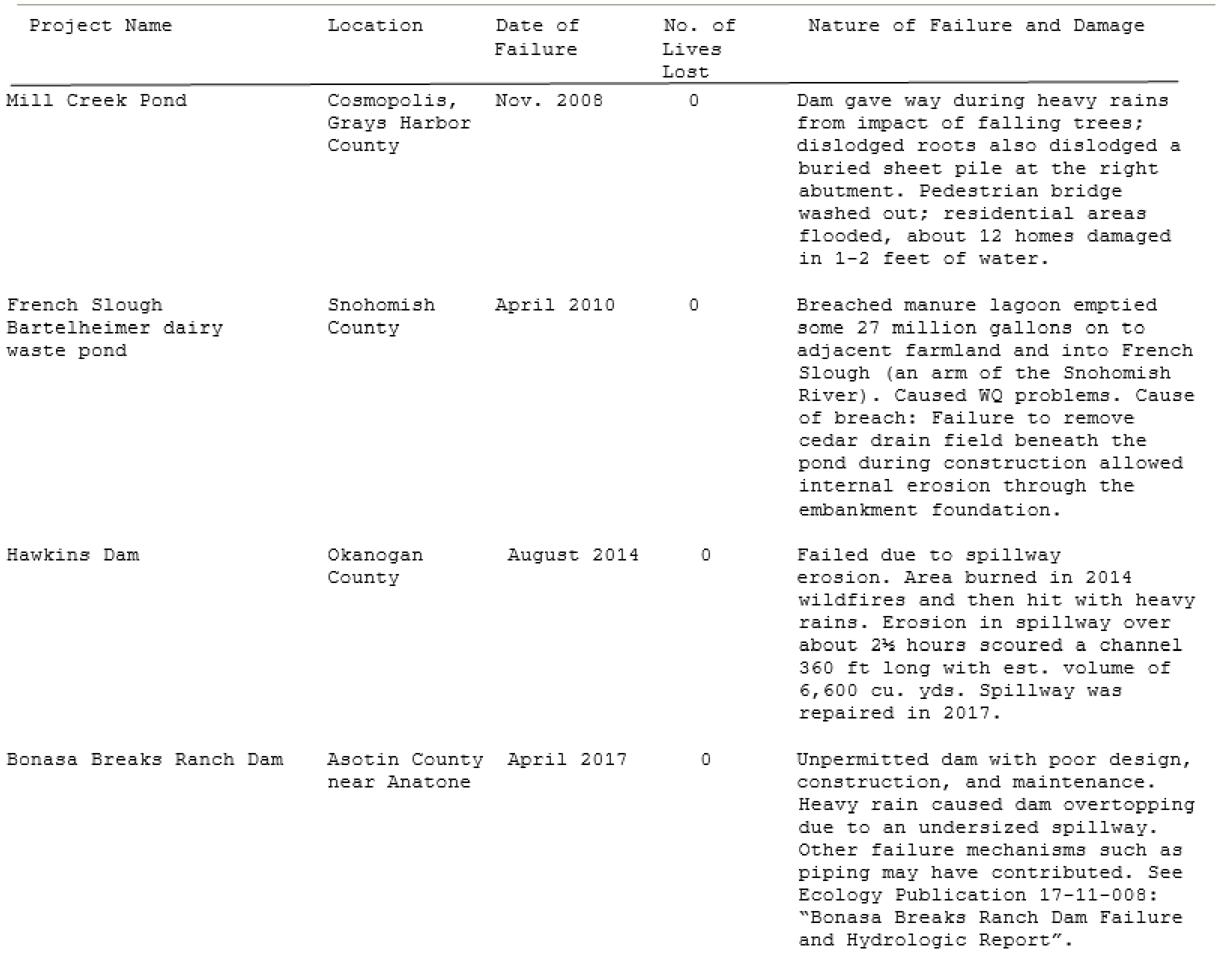
Project Name	Location	Date of Failure	No. of Lives Lost	Nature of Failure and Damage
Masonry Dam (Boxley Burst)	Near North Bend	December 1918	0	Excessive seepage through glacial moraine abutment caused mud flow about 1 mi. from reservoir. Destroyed RR line and village of Eastwick.
Eastwick RR Fill Failure	Near North Bend	February 1932	7	Blockage of culvert by slide caused RR Fill to back up water and fail. Destroyed RR line and village of Eastwick.
Loup Loup Dam	Near Malott	April 1938	0	50 foot high hydraulic fill dam failed when emergency spillway was undercut during a flood. Destroyed 25 homes and left 75 people homeless. Destroyed 1/2 mile of state highway.
Lake Dawn Dam	Port Angeles	February, 1950	0	Heavy rains caused overtopping and failure of earthen dam. 1 home destroyed, $4000 damage
North Star Sand & Gravel Dams	Everett	December 1967	0	40 foot high dam washed out by overtopping due to lack of spillway. 25 foot high dam rebuilt, also failed, washed out GN railroad tracks, derailed passing train.
Pillar Rock Dam	Wahkiakum County	January 1970	0	Logging roadfill culvert blocked by debris, overtopped and failed, caused 25 foot high concrete gravity dam to fail. 3 homes and fish cannery destroyed.
Sid White Dam	Near Omak	May 1971	0	Earthen dam failed due to seepage through animal burrows. Caused second dam to fail and dumped debris into town of Riverside.
Horseshoe Lake Blowout	Chewelah	May 1974	0	Outlet tunnel through 50 foot high natural ridge collapsed causing ridge to fail. Drained 20 foot deep lake. Extensive flood damage and debris deposits on cropland in downstream valley.



Notable Dam Failures and Incidents in Washington State

Project Name	Location	Date of Failure	No. of Lives Lost	Nature of Failure and Damage
White River Incident	Near Auburn	July 1976	2	Surge in flow caused by increased discharge from Mud Mountain Dam and removal of flashboards at PP&L Diversion Dam. Killed 2 children playing in White River.
Alexander Lake Dam	Near Bremerton	December 1982	0	Spillway undermined and failed during heavy rains. Caused damage at fish hatchery and homes in Gorst.
Upriver Dam	Spokane	May 1986	0	Hydropower facility failed by overtopping. Lightning struck system, turbines shut down. Water rose behind dam while trying to restart. Backup power systems failed, could not raise spillway gates in time. Caused $11 million damage to facility.
Chinook Dam	Pacific County	November 1990	0	Heavy rains overtopped the embankment and undermined the spillway, leading to failure of dam. Approximately $100,000 damage to facility.
Seminary Hill Reservoir City of Centralia	Centralia	October 1991	0	Failure along weak rock zone in hillside caused massive slide which breached reservoir. 3 million gallons of water drained from reservoir in 3 minutes. 2 homes destroyed, many homes damaged, $3 million in damage.
Iowa Beef Processors Waste Pond Dam No. 1	Wallula near Richland	January 1993	0	Failure of 15-foot high embankment released 300 acre-feet of waste water. Failure attributed to high reservoir levels due to snowmelt, entering animal burrows near embankment crest, and eroding dam. Washed out Union Pacific RR tracks, derailed 5 locomotives. $5 million in damage.
Broetje Orchards Block 96 Reservoir	Walla Walla County	April 2000	0	Failure of 26-ft high embankment released 11m gallons of water; impacted residential youth camp and Blue Mt. Railroad line. Failure due to leak in PVC liner and internal erosion along pipeline through the embankment.

Notable dam failures and incidents in Washington State (in chronological order)



Project Name	Location	Date of Failure	No. of Lives Lost	Nature of Failure and Damage
Mill Creek Pond	Cosmopolis, Grays Harbor County	Nov. 2008	0	Dam gave way during heavy rains from impact of falling trees; dislodged roots also dislodged a buried sheet pile at the right abutment. Pedestrian bridge washed out; residential areas flooded, about 12 homes damaged in 1-2 feet of water.
French Slough Bartelheimer dairy waste pond	Snohomish County	April 2010	0	Breached manure lagoon emptied some 27 million gallons on to adjacent farmland and into French Slough (an arm of the Snohomish River). Caused WQ problems. Cause of breach: Failure to remove cedar drain field beneath the pond during construction allowed internal erosion through the embankment foundation.
Hawkins Dam	Okanogan County	August 2014	0	Failed due to spillway erosion. Area burned in 2014 wildfires and then hit with heavy rains. Erosion in spillway over about 2¾ hours scoured a channel 360 ft long with est. volume of 6,600 cu. yds. Spillway was repaired in 2017.
Bonasa Breaks Ranch Dam	Asotin County near Anatone	April 2017	0	Unpermitted dam with poor design, construction, and maintenance. Heavy rain caused dam overtopping due to an undersized spillway. Other failure mechanisms such as piping may have contributed. See Ecology Publication 17-11-008: "Bonasa Breaks Ranch Dam Failure and Hydrologic Report".

Probability of Future Occurrences

Since 1970, there has been, on average, a dam failure about every three years. Given that many of Washington's dams have reached their design life, it can be expected that the rate of failure could remain the same or grow. However, the improved understanding of dams and dam failure mechanisms achieved over the same period of time will allow dam managers to more readily identify and correct conditions that could lead to failure. Furthermore, the advancement in technologies to develop inundation maps coupled with improved communication options such as social media, will help reduce the impact should a dam failure occur.

Dam failure can occur with little warning by earthquakes and intense storms that may produce a flood in a few hours or even minutes which can overwhelm a dam. Other failures can take much longer to occur, from days to years, as a result of lack of maintenance, improper operation, poor design and construction, vandalism or terrorism. Washington state provides laws, regulations, written guidance, periodic inspections and technical assistance to help reduce the probability of either type of dam failures.

The first dam safety law in Washington was passed as part of the state Water Code in 1917 (RCW 90.03.350). This law required that engineering plans for any dam that could impound 10 or more acre-feet had to be reviewed and approved by the state before construction could begin. Over the years, the Department of Conservation and Development, then the Department of Water Resources, and now the Department of Ecology performed this function. This is the first line of defense in reducing the probability of dam failure. Dam safety regulations in Chapter 173-175 RCW require the plans to be prepared by a professional engineer licensed in Washington state. The DSO conducts inspections during construction to ensure new and modified dams are being built to the standards prescribed in the plans.

After a dam is constructed, state regulations require the owner to have an operation and maintenance plan which describes, in part, how the dam will be operated and maintained to ensure safety. The failure to implement a suitable operation and maintenance program at dams is a common thread in dam incidents occurring in Washington. Some dam owners, including many municipalities, operate older reservoir systems that require increasing maintenance. At times, it can be difficult to get funding for an effective operation and maintenance program.

Operation and maintenance plans include inspections by the owner on an annual basis to catch problems early and regularly. For significant and high-hazard dams, the DSO engineers conduct an inspection every five years. The inspections often include a review and analysis of available data on design, construction, operation and maintenance of the dam and its appurtenances; visual inspection of the dam and its appurtenances; evaluation of the safety of the dam and its appurtenances, which may include assessment of the hydrologic and hydraulic analyses, stability analyses and other conditions which could constitute a hazard to the integrity of the structure; evaluation of the downstream hazard classification; evaluation of the operation, maintenance and inspection procedures employed by the owner and/or operator; and review of the emergency action plan for the dam including review and/or update of dam breach inundation maps. The Department of Ecology prepares a report of the findings of the dam inspection and any required remedial work to be performed. Once deficiencies are identified, the dam owner is responsible for correcting those deficiencies. If the owner fails to correct deficiencies at the dam, the dam can be declared a public nuisance and removed through an abatement proceeding in Washington Superior Court.

Dam owners of high and significant hazard dams must also have an Emergency Action Plan (EAP). An EAP is a formal but simple plan that identifies potential emergency conditions that could occur at a dam, and prescribes procedures to follow to minimize loss of life and the potential for property damage.

Should a situation develop that impacts the integrity of a dam, an EAP provides clear steps to take and guides communication to the appropriate people and offices. Increasing the level of disaster preparedness, including evacuation routes, notification procedures, and personal preparedness training and hazard awareness in communities downstream from high-hazard dams play a factor in lessening the outcome of a dam failure, should one occur.

The DSO maintains a website that provides guidance documents and technical manuals for managing a dam as discussed above. All of these have the common purpose of helping dam owners operate their dams safely. This information can be accessed at: https://ecology.wa.gov/Regulations-Permits/Guidance-technical-assistance/Dam-operation-maintenance-guidance

Causes of Dam Failures

Based on national statistics, the following data provides the probability of different failure mechanisms:

Overtopping - 34% of all failures

- Inadequate spillway design
- Debris blockage of spillway
- Settlement of dam crest

Foundation defects - 30% of all failures

- Differential settlement
- Sliding and slope instability
- High uplift pressures
- Uncontrolled foundation seepage

Piping and seepage - 20% of all failures

- Internal erosion through dam caused by seepage or piping
- Seepage and erosion along hydraulic structures such as outlet, conduits or spillways, or leakage through animal burrows
- Cracks in dam

Conduits and valves - 10% of all failures

- Piping of embankment material into conduit through joints or cracks

Other - 6% of all failures

Drought Risk Summary

Washington State Risk Index for Drought (WaSRI-D)	🟧
LIKELIHOOD	🟧
Difficult to predict future probability of droughts, but it is expected with the changing climatic conditions the state may likely experience one or two major drought events. This will exacerbate by expected low spring/summer discharges.	
HAZARD AREA	HIGH
75 percent of the State area is exposed to medium or higher levels of drought.	
POPULATION	
About 21 percent of the State population resides in areas with medium or higher drought exposure.	
VULNERABLE POPULATION	
Less than 5 percent of the State population resides in areas ranked medium or higher on social vulnerability and also are exposed to medium or higher drought hazards.	
BUILT ENVIRONMENT	
Drought does not pose any significant threat to the built environment. Therefore, no detailed assessment is included for this sector.	
CRITICAL INFRASTRUCTURE	
Drought does not pose any significant threat to the critical infrastructure facilities included in this risk analysis. Therefore, no detailed assessment is included for this sector.	
STATE FACILITIES	
Drought does not pose any significant threat to the State facilities. Therefore, no detailed assessment is included for this sector.	
FIRST RESPONDERS	
Drought does not pose any significant threat to the first responder facilities. Therefore, no detailed assessment is included for this sector.	
ECONOMIC CONSEQUENCES	HIGH
Counties ranked medium or higher on WaSRI-D account for about 70 percent of real State GDP.	
ENVIRONMENTAL IMPACTS	MEDIUM
An important risk from drought is the increased susceptibility to wildfires. Drought conditions can lead to decrease in short-term water availability and soil productivity.	

Hazard Description

Drought is a prolonged period of dryness severe enough to reduce soil moisture, water and snow levels below the necessary levels for sustaining plant, animal and economic systems. It decreases available water in reservoirs, lakes, streams and aquifers for people and nature. Droughts are part of the climate cycle but can be worsened by a variety of factors. They are an expected phase in the climatic cycle of almost any geographical region. In the past 100 years in the United States, there have been three periods of large scale droughts. The first was the Dust Bowl of the 1930s. In the 1950s, another drought impacted the South, Southwest and Plains areas. The third period has been occurring in recent decades.

Drought is the most complex but least understood of natural hazards, affecting more people than any other hazard (Hagman 1984). Drought is a unique natural hazard due to many reasons. First, the onset and the end of drought is difficult to determine (Tannehill 1947). The effects of drought often accumulate slowly over a considerable period and may linger for years after the termination of the event. Because of this, drought is often referred to as a creeping phenomenon (Tannehill 1947). Second is the absence of a precise and universally accepted definition of drought, which adds to the confusion about whether a drought exists and, if it does, its degree of severity. Realistically, definitions of drought must be region and application (or impact) specific (Wilhite and Grant 1985). Third, drought impacts are nonstructural and spread over larger areas in comparison to most of the other natural hazards. This represents a big challenge for emergency managers as they are more accustomed to dealing with localized and structural impacts that require mobilization response to restore communication, transportation channels, provision of medical and food supplies, and so on. These characteristics of drought ultimately hinder development of accurate, reliable and timely estimates of extent, duration and severity of droughts (Wilhite et. al. 2007).

According to the National Drought Mitigation Center (NDMC), drought “originates from a deficiency of precipitation over an extended period, usually a season or more. This deficiency results in a water shortage for some activity, group or environmental sector.” What is clear is that a condition perceived as “drought” in a given location is the result of a significant decrease in water supply relative to what is “normal” in that area. Washington State is one of the few states to have a statutory definition of drought (Revised Code of Washington Chapter 43.83B.400). Drought is defined as (1) the water supply for the area is below 75 percent of normal and (2) water uses and users in the area will likely incur undue hardships because of the water shortage.

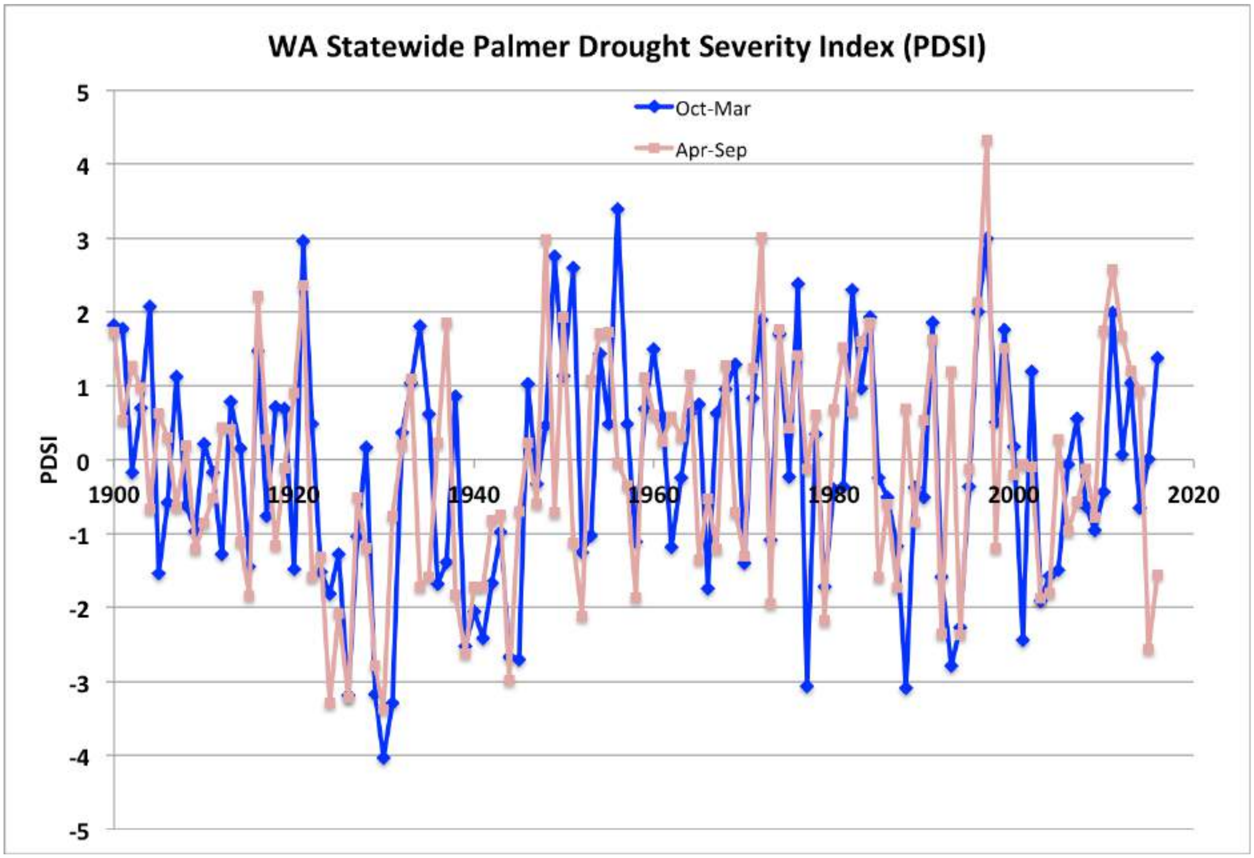


FIGURE D1: TIME SERIES OF PALMER DROUGHT SEVERITY INDEX (PDSI) FOR WASHINGTON STATE, 1900-2016 (SOURCE: WASHINGTON DROUGHT CONTINGENCY PLAN)

There are four generally accepted, operational definitions of drought (NDMC, 2006):

Meteorological drought is usually an expression of precipitation's departure from "normal" over some period. These definitions are usually region-specific and presumably based on a thorough understanding of regional climatology. The variety of meteorological definitions from different countries at different times illustrates why it is folly to apply a definition of drought developed in one part of the world to another:

- United States (1942): less than 2.5 mm of rainfall in 48 hours
- Great Britain (1936): 15 consecutive days with daily precipitation totals of less than 0.25 mm
- Libya (1964): annual rainfall less than 180 mm
- India (1960): actual seasonal rainfall deficient by more than twice the mean deviation
- Bali (1964): a period of 6 days without rain meteorological measurements are the first indicators of drought

Agricultural drought occurs when there is not enough soil moisture to meet the needs of a crop at a time. Agricultural drought happens after meteorological drought but before hydrological drought. Agriculture is usually the first economic sector to be affected by drought.

Vulnerabilities (from WA Drought Contingency Plan):

- A large portion of the state's agricultural production is in the Yakima Valley where irrigation is necessary for nearly all crops and post-1905 water rights are pro-ratable in low water years.
- Areas where farmers rely on rain to water crops or support foraging have little or no recourse when the rain doesn't come. If forced to purchase feed to support livestock, they must also pay premium prices as demand is high.
- Fruit trees—particularly apples—need reliable water supplies or the tree itself is lost as well as the year's crop. This results in costs from the removal of dead trees, the purchase and planting of new trees, and years of lost revenue waiting for new trees to mature and bear fruit.
- Potatoes are a high-water demand crop and a top producer of agricultural profits in four counties.
- Berries with inadequate water produce fewer and smaller fruit with reduced quality. This is a pattern among many farmers during the 2015 drought: reduced production, of lesser quality, with higher expense.
- Nursery stock growers may be challenged to keep plants healthy, while the market for the plants falls dramatically.
- Growers also report higher costs for pest and weed control.

Hydrological drought refers to deficiencies in surface and subsurface water supplies. It is measured as streamflow and as lake, reservoir and groundwater levels. There is a time lag between lack of rain and less water in streams, rivers, lakes and reservoirs, so hydrological measurements are not the earliest indicators of drought. When precipitation is reduced or deficient over an extended period, this shortage will be reflected in declining surface and subsurface water levels.

Climate change will cause hotter and dryer summers with reduced summer river discharges. This will contribute to the frequency and intensity of hydrological drought conditions.

Energy-Sector Vulnerability (from WA Drought Contingency Plan):

- Reduced volume of streamflow and reservoir storage due to drought reduces hydropower generation.
- Ordered spill rates for fish flows can have a large impact on the water available for power generation.

Washington State's power supply framework is highly resilient to drought impact due to existing, long-standing coordination agreements between power producers that facilitate the exchange of power from a common pool. Although hydropower typically provides about half the electrical power demand in the region, generation in the Northwest is diversified and, over time, has become increasingly less dependent on hydroelectric energy.

Fish, Wildlife, and Environmental Vulnerability (from WA Drought Contingency Plan):

- Low flows expose physical blockages to migration and can strand migrants in dewatered stream segments.
- Low flows or reservoir levels shrink habitat, causing crowding, low dissolved oxygen, disease, less food available, and higher mortality of juvenile and adult fish.
- High stream temperatures, due to low flow and/or higher air temperatures, can kill fish and create thermal blockage which upstream migrants will not pass.
- Low flows reduce riffle depth or dry up stream reaches, preventing upstream migrants from entering streams or reaching normal spawning grounds.
- Low flows shrink spawning habitats, leading to low egg survival.
- Reservoir outflows can be curtailed by drought conditions, causing low-flow problems downstream.
- Disease organisms become more virulent at lower flows and higher water temperatures.
- Usual water sources may become limited, unavailable or of inadequate water quality.
- Hatchery conditions may require fish to be released earlier or relocated to safe havens, increasing costs, handling stress and mortalities.
- Terrestrial water shortages for birds, small game and big game.
- Impacts to waterfowl, amphibians and other species as wetlands recede.
- Loss of forage grasses and shrubs.
- Increased disturbance, road kill, predation, and incidents of problem and dangerous wildlife as animals are forced to seek water and food near more populated areas.

Socioeconomic drought occurs when physical water shortage starts to affect people, individually and collectively. Or, in more abstract terms, most socioeconomic definitions of drought associate it with the supply and demand of an economic good.

It should be noted that water supply is not only controlled by precipitation (amount, frequency and intensity), but also by other factors including evaporation (which is increased by higher than normal heat and winds), transpiration and human use.

Washington State has experienced several droughts lasting more than a single season: 1928-32, 1992-94 and 1996-97. Since the turn of the century, there have been three major droughts in 2001, 2005 and 2015 in the state. Washington's natural systems have been impacted along with the hydropower, agricultural and outdoor recreation sectors. The 2015 drought also coincided with the worst wildfires in Washington State history, which burned more than one million acres of land.

Water System Vulnerability (from WA Drought Contingency Plan)

Risk factors for public water systems include:

- Single source
- Shallow well depth
- Aged well construction and appurtenant equipment
- Excessive system leakage
- Low operational capacity (GPM)
- Lack of system redundancy
- Treatment concerns

The Cascade Mountain range divides the wet western half of Washington State from the dry eastern half. Clouds release rain and snow in the west before passing over the mountains. The mountains store snowpack that is a vital water source for the state. Unlike many other states, snow – not built reservoirs – is the primary form of water storage in Washington. Snow accumulation is impacted by temperature and precipitation in the winter months along with El Niño. In El Niño years, temperatures tend to be warmer and winters drier. The result is lower snowpack in the spring and diminished stream flows in snowmelt driven rivers.

Washington's Drought Contingency Plan

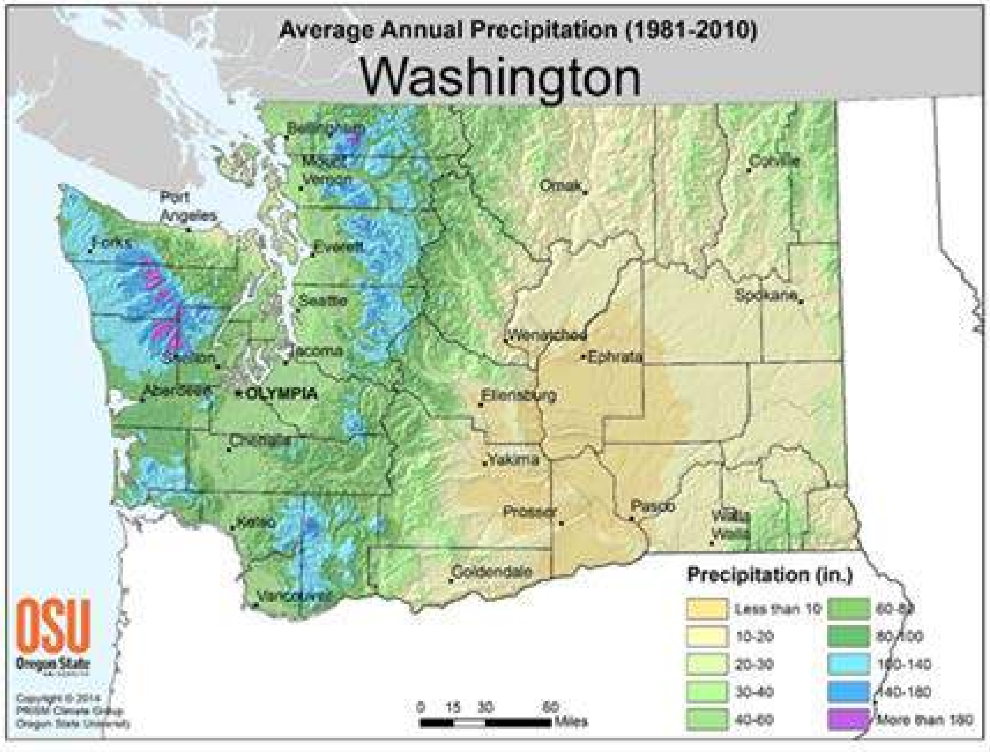
The Washington State Drought Contingency Plan was prepared for the "purpose of guiding state agencies who are responsible for planning and responding to drought conditions in the state." This document contains several sections excerpted from the Drought Plan, 2018 update. EMD, the lead agency for mitigation planning, and ECY, the lead agency for drought, support each other on both plans.

The Drought Plan looks at "mitigation" somewhat differently than all-hazards plans. Mitigation is a lessening of the current incident (as opposed to increasing long-term response capability or reducing risk).

The lead agency for drought response is the Washington Department of Ecology (ECY). They work with the federal government, other state agencies, local utilities, tribes, farmers and conservation groups. ECY issues curtailments, emergency drought permitting and boosts stream flows. The Water Supply Availability Committee (WSAC) monitors water supply and identifies drought conditions. If drought becomes a significant concern, the Executive Water Emergency Committee (EMEC) is activated. This Committee makes recommendations to the Governor who in turn directs ECY. The State also has a Drought Contingency Plan. In addition to the State Drought Contingency Plan, public water systems develop water shortage response plans. Local governments and agencies can declare Water Emergency Declarations and Outdoor Water Use Restrictions with penalties.

Drought Hazard Location, Extent and Magnitude[1]

Like other western states, Washington relies on surface water for about three-quarters of total freshwater withdrawals—the majority of which is sustained in warm seasons by melting snowpack. Ground water accounts for the remaining one-quarter of Washington's water supply.



Washington is split by the Cascade Mountains into two distinct climates. The region west of the mountains receives about 50 inches of precipitation on average annually—about four times higher than the drier eastern region. The eastern and southwestern regions of Washington are situated in the Columbia River drainage basin. The Columbia River is important for irrigation, aquatic habitat and hydropower generation in Washington.

Differences in precipitation can be dramatic. Forks, on the west side of the Olympic Peninsula, averages 119 inches of rain annually while Prosser, in Benton County, receives an average of less than 9 inches.

Temperature regimes vary from the west to the east side as well. West of the Cascades, the average January maximum temperature ranges from 40° F in the lower elevations to 30° F at the 5,500-foot elevation. Minimum temperatures range from 30° F in the lower elevations to 20° F in the higher

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[1] Significant portions of this section are excerpted, in-full, from the Washington State Drought Contingency Plan.

elevations. On the east slope of the Cascades, the average January maximum temperature varies from 25° to 35° F and the minimum temperature from 15° to 25°.

The crest of the Cascades divides the state hydrologically as well. The warmer, wetter conditions on the west side mean that winter snows are more transient and confined to higher elevations. To the west, multiple watersheds discharge directly to Puget Sound, the Strait of Juan de Fuca, the Pacific Ocean, and to the Columbia River. West of the Cascades at lower elevations, the geology consists largely of unconsolidated glacial deposits containing extensive groundwater aquifers. These aquifers recharge quickly in response to fall-winter precipitation.

East of the Cascades, every river within Washington drains to the Columbia River. The Columbia Plateau is largely characterized by extensive layers of Columbia River basalts. Beyond alluvial areas adjacent to rivers, groundwater is often scarce and found at greater depths. These aquifers receive less annual recharge from precipitation, and thus are more vulnerable to years of heavy pumping, during which the volume of withdrawal exceeds the volume of recharge. Much of the Columbia Basin is already experiencing significant declines in groundwater levels.

Washington's watersheds can be classified according to their ratio of precipitation in the form of snow versus rain. This information informs their exposure and sensitivity to drought conditions, as driven by above-normal temperatures, below-normal precipitation, or some combination of both. Watersheds that normally receive substantial snowpack are likely to be more sensitive to warm winters than other watersheds.

Snow dominant watersheds are areas where the ratio of April 1 snowpack (snow water equivalent, SWE) to Oct-March total precipitation is high (above 40 percent). In other words, at least 40 percent of the precipitation that falls during those six months remains stored in snowpack on April 1. For rain dominant watersheds, less than 10 percent of their October-March precipitation is stored as snow, while the range is 10-40 percent for mixed rain and snow basins. In warmer than normal years, precipitation falls more as rain than snow as the freezing level rises. Because precipitation is not retained at higher elevations in the form of snow, more runoff is prone to occur during the winter months, rather than during the spring and early summer snowmelt.

Future water availability in the state is projected to decline, owed in part to climate change and resultant declines in snowpack (Barnett et al. 2008; Elsner et al. 2010). Common indicators of drought include precipitation, streamflow and current soil moisture (SM). However, long-term SM (and to a lesser extent, streamflow for unregulated streams) observations across the United States are scarce. Therefore, SM and runoff datasets produced by the land surface models (LSMs) that make up the North American Land Data Assimilation System have become a valuable source of information for drought monitoring and prediction (Mo 2008). The LSMs produce nowcasts (model representations of current hydrologic conditions) that simulate the time lag between precipitation (deficiency), SM and runoff deficiencies. These latter two variables are directly related to the availability of water for agricultural and municipal users. A strength of LSM-based indicators is that they can be aggregated to any geographical area, such as counties, watersheds or hydroclimate zones. Indicators such as the Palmer Drought Severity Index (PDSI; Palmer 1965) are usually calculated at the relatively coarse spatial resolution of the National Oceanic and Atmospheric

Administration (NOAA) climate divisions but provide a good and quick way to predict future drought events.

Three "Flavors" of Drought

Bumbaco and Mote (2010) used the water years (Oct through Sept) of 2001, 2003, and 2005 to illustrate three distinct types or "flavors" of recent drought in Washington State:

1) Low winter precipitation
2) Dry summer
3) Warm winter temperatures

The first, in 2001, had low winter snowpack caused by low winter precipitation, and had most of its impacts in the spring and summer. In addition to the generally low streamflow in the winter (Dec-Feb), the snowmelt-dominated streams in the state (mostly in Eastern Washington) had stream flows during summer (June-September) that ranked among the 5 lowest in 55 years.

The second flavor of drought – the dry summer drought – occurred in Washington in the summer of 2003 because of the second warmest and second driest (at the time of journal publication) July-August period for Washington and Oregon combined. Even though summers are typically dry in the region, there were record or near-record low flows during the June-September period for streams that are not snowmelt dominated. The fire season was also particularly bad in Oregon and British Columbia, but Washington was mostly spared.

The last flavor of drought – and the one that is particularly relevant to 2015, was the drought of 2005. Warm winter temperatures decreased the snowpack, leading to both winter and summer drought. Precipitation in the Washington Cascades was between 70 and 80 percent of normal during the winter, but due to the higher-than-normal temperatures, snowpack was only 20 percent of normal for much of the winter. Late winter storms were accompanied by such warm temperatures that snow water content declined even at the highest elevations monitored.

A graphic depicting the statewide monthly temperature and precipitation anomalies for the years 1977, 2001, 2005, and 2015 is included below. Note the extremely warm temperatures that played a key role in the 2015 drought, causing the near-normal precipitation to fall as rain rather than snow in the mountains. This occurred to some extent in 2005, when a few intervals of warm, wet weather associated with atmospheric rivers depleted snowpack (Bumbaco and Mote 2010) while the rest of the season had periods of lesser precipitation and near-normal temperatures. Other droughts in Figure 3 (1977 and 2001) were largely driven by lack of winter precipitation rather than extreme temperatures.

Global warming is changing these conditions. Winters are becoming warmer and wetter and summers hotter and drier with reduced summer precipitation. The State's Cascadia drainages are changing from snow/rain dominated systems to rain dominated ones, thereby losing their spring/summer peak discharges. These lower summer flows are increasing prairie expansion.

Drought Indicators

Drought is commonly characterized based on key hydrological variables such as precipitation, streamflow and soil moisture (SM). Additionally, drought can also be characterized by temporal extent and persistence (Shukla et. al. 2011). SM and runoff datasets produced by the land surface models (LSMs) that make up the North American Land Data Assimilation System (NLDAS) are a valuable source of information for drought monitoring and prediction (Mo 2008). The LSMs produce model representations of current hydrologic conditions (nowcasts) that simulate the time lag between precipitation (deficiency) and SM and runoff deficiencies. These variables are directly related to the availability of water for agricultural and municipal users, and can be aggregated to any geographical area, such as counties, watersheds or hydroclimate zones. In contrast, the traditional indicators such as the Palmer Drought Severity Index (PDSI; Palmer 1965) are usually calculated at the relatively coarse spatial resolution of the National Oceanic and Atmospheric Administration (NOAA) climate divisions. It is important to note that the impact of drought does not only depend on the hydrological variables, but also on the duration and the potential uses of water in the region. For example, SM deficiencies with durations as short as 1 month can also result in significant impact on agricultural productivity if they occur during the peak period of crop water use.

Past Occurrences and Future Likelihood

According to the National Weather Service, there have been 19 drought occurrences in Washington state since 1900. The longest duration of droughts has ranged from 34 to 72 months in 10 meteorological regions of the state. In the last two decades, Washington State has experienced two major droughts. A statewide drought emergency was declared on March 14, 2001 and on March 10, 2005; in both cases, water levels were less than 75 percent of the normal water supply and expected to cause undue hardship. Both droughts also inflicted significant impacts throughout the state, which included the following: increased production costs and reduced revenue in the agricultural sector; reduced deliveries to junior water rights holders; reduced power generation; increased power costs; reduced survival of adult and juvenile salmonid; and reduced visitation to ski areas. Estimates of drought damages to agriculture ranged from $270 million - $400 million in 2001 and $195 million - $299 million in 2005 (Stephens et al., 2005).

In 2015, the Governor declared drought on March 13 for three regions of the State—the Olympic Peninsula, the east slopes of the central Cascades, and the Walla Walla Basin. The drought declaration was extended on April 17, 2015, to include more watersheds, and then was extended statewide on May 15, 2015. In July 2015, the Washington State Legislature approved $16 million for Ecology to support drought relief work for the biennium.

Unlike classic droughts, characterized by extended precipitation deficits, 2015 was the year of the “snowpack drought.” Washington State had normal or near-normal precipitation over the 2014-2015 winter season. However, October through March, the average statewide temperature was 40.5 degrees Fahrenheit, 4.7 degrees above the 20th century long-term average and ranking as the warmest October through March on record. Washington experienced record low snowpack because mountain precipitation that normally fell as snow instead fell as rain.

The snowpack deficit then was compounded as precipitation began to lag normal levels in early spring and into the summer. With record spring and summer temperatures, and little to no precipitation over many parts of the state, the snowpack drought morphed into a traditional precipitation drought, impacting crops and aquatic species. Many rivers and streams experienced record low flows.

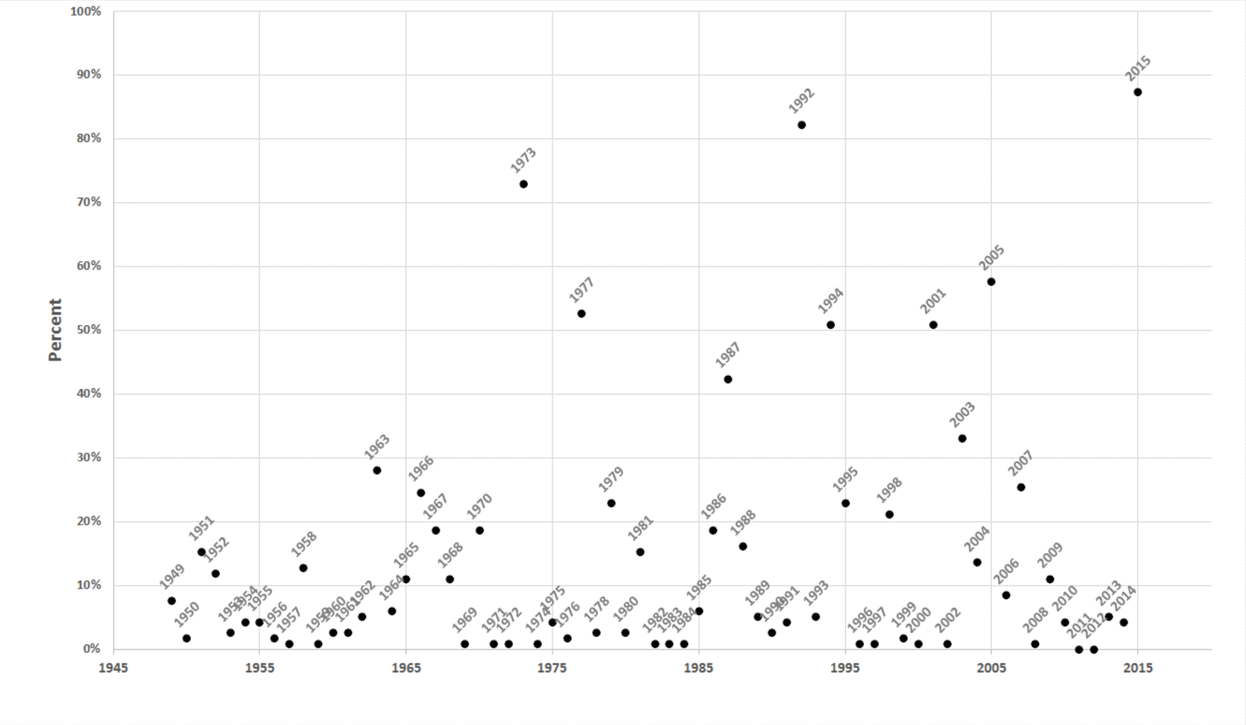

FIGURE D3: PERCENT OF RIVER STATIONS BELOW 75% OF NORMAL, 1942-2015 (SOURCE: WASHINGTON DROUGHT CONTINGENCY PLAN, NATIONAL RIVER FORECAST CENTER)

Predicting future probability of a drought is difficult because of the number of variables involved in modeling the underlying climatic conditions. Whether a drought will occur (and how long it will last) depends on a huge number of factors including atmospheric and ocean circulation, soil moisture, topography, land surface processes, and interactions between the air, land and ocean which ultimately influence temperature and precipitation. Predicting drought depends on the ability to forecast these two fundamental meteorological surface parameters, precipitation and temperature. From the historical record we know that climate is inherently variable, and that anomalies of precipitation and temperature may last from several months to several decades. But, given the number of variables involved it is difficult to predict future drought events. However, drought forecasting continues to improve with better data availability and modeling improvements.

A monthly drought outlook is published by the National Weather Service's Climate Prediction Center at the end of each month, which provides a drought forecast for the following month for all 50 states and Puerto Rico (http://www.cpc.ncep.noaa.gov/products/). Weekly drought conditions across the country are provided by the U.S. Drought Monitor, a government-university collaboration hosted by the University of Nebraska, Lincoln (http://droughtmonitor.unl.edu/). The Drought Monitor also provides many other tools and resources, including maps that show changes in drought conditions over time.

Climate change is and will continue to increase the likelihood of drought conditions. Two of the three distinct types of favorable drought conditions within Washington State are being changed - Low winter precipitation rate will vary normally, but winters will be warmer and summers drier.

Periods of low winter precipitation are not expected to decrease. Similarly, projected annual precipitation rates will experience little change in seasonal variations. However, winters are, and will continue bring, more frequent intense periods of rain fall. Less snow will be available to feed rivers during summer month due to warmer winter temperatures. Accordingly, most rivers will be drier.

Relationship to other Hazards and Key Impacts

Shortfall in the normal expected precipitation in a region results in drought conditions. The severity and the duration of the drought is dependent on the timing, persistence and the spatial variation in the shortfall. Lack of precipitation can result in increased susceptibility to wildfires in watershed experiencing drought conditions. For example, the wildfires that accompanied the 2015 drought in Washington State resulted in an estimated $178 million in losses. Other key impacts of drought conditions are most evident in municipal water supply systems, agriculture, and hydro-power generations.

Municipal Water Supply - Washington State has 5.5 million residents served by public water systems and an additional 725,000 served by private wells regulated by local public health agencies. Drought reduces water supplies and can have variable impacts depending on the local water supply system. In droughts, local water utilities may need to rely on additional supplies from pumping backup wells.

Agriculture - Washington State’s agricultural production was $10.6 billion in 2016. The state ranks in the top three for the production for a wide variety of agricultural products. The state ranks number one in the nation in the production of apples, hops, pears, sweet cherries and several other items. Agriculture and food processing together provide more than 164,000 jobs. Washington State’s more than 35,900 farms are spread across every county. There are 1.8 million irrigation acres and 80 percent of state water withdrawals are for agriculture. Droughts can result in significant loss of crops and farm income, and have a cascading effect on workers and other related industries. At the height of the 2015 drought, 85 percent of the state was in ‘extreme drought status’ in August. The Washington Department of Agriculture estimates losses at between $633 and $773 million.

Drought impacts vary by crop, region and water rights. Perennial crops, such as fruit trees and hops, may take many years to return to normal production. Fontaine and Steinemann (2009) conducted a drought vulnerability assessment for 34 sub-sectors in Washington State based on telephone interviews with 67 designated key representatives of the six regions of the State. In this study, vulnerability was ranked the highest for: dryland farmers in the south central and east regions; fisheries in the south central and north central regions; ski area operators and the green industry in the western regions; berry farmers in the southwest/Olympic Peninsula region; and farmers with junior water rights in the south-central region. These sub-sectors thus represent key areas for policy intervention for enhancing their ability to withstand prolonged periods of drought.

Hydropower - Washington State generates nearly 69 percent of its energy from hydropower. ECY projects that lower water supplies will lead to a nine to 11 percent decrease in hydropower production. The less water there is in reservoirs, the less energy can be generated as water is released. Warmer summers and population growth result in an increase in energy needed for air conditioning. The reduction in hydropower can lead to the use of more fossil fuels and increased energy prices.

Drought Risk Assessment

Drought risk assessment is based on drought hazard values derived from the National Drought Mitigation Center's U.S. Drought Monitor. Hazard values are the maximum number of weekly drought polygons overlapping a given census tract for the period of record (2000-2016). Drought polygons classified as "Moderate," "Severe," "Extreme," or "Exceptional" were merged into a statewide, 17-year weekly drought polygon dataset. Drought polygons were overlaid on a nationwide 49-kilometer grid and grid cells containing the maximum number of overlapping weekly drought extents in each census tract were selected and the corresponding number of overlapping drought extents was assigned as its drought hazard value. The count was ranked on a scale of 1 to 5 (1-low, 2- Medium-Low, 3- Medium, 4-Medium-high, and 5- High) based on z-score transformation (standard deviations from the mean).

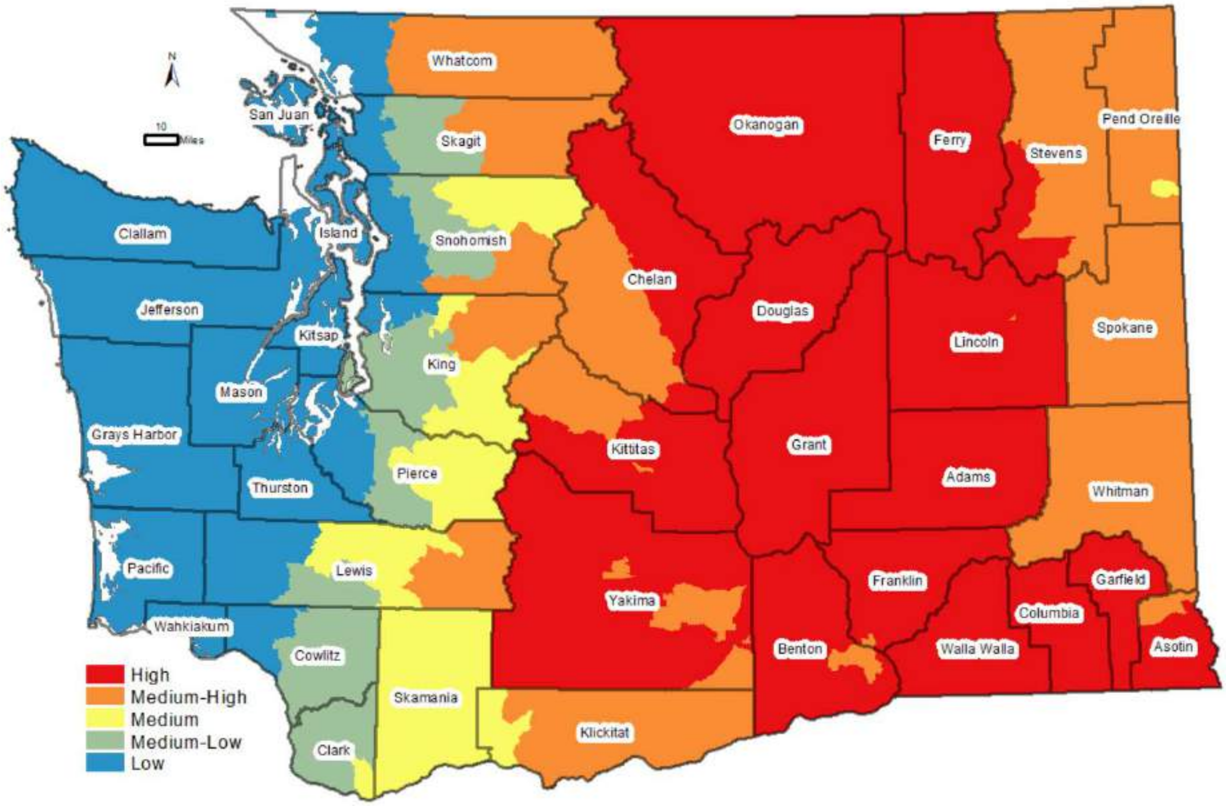

FIGURE D4: DROUGHT HAZARD IN WASHINGTON STATE

Area Exposure

The drought hazard zones were overlaid with the county map to estimate the area exposed to possible tsunami inundation in each county. Overall, about 75 percent of the total land area of the state is estimated to be at medium or higher exposure from droughts. All census tracts in Adams, Asotin, Benton, Chelan, Columbia, Douglas, Ferry, Franklin, Garfield, Grant, Kittitas, Klickitat, Lincoln, Okanogan, Pend Oreille, Skamania, Spokane, Stevens, Walla Walla, Whitman, and Yakima counties are ranked medium or higher for drought exposure. There is high drought exposure in the Western and Central parts of the State. Coastal areas have significantly lower exposure to droughts. Among the coastal counties – King, Lewis, Skagit, and Snohomish – the drought exposure ranges from 50-56 percent of the county area.

Percentage of County Land Area with Medium or Higher Drought Exposure	
County	Percent County Area in Drought Hazard Zone
Adams	100.00
Asotin	100.00
Benton	100.00
Chelan	100.00

Percentage of County Land Area with Medium or Higher Drought Exposure	
County	Percent County Area in Drought Hazard Zone
Clallam	0.00
Clark	10.23
Columbia	100.00
Cowlitz	0.00
Douglas	100.00
Ferry	100.00
Franklin	100.00
Garfield	100.00
Grant	100.00
Grays Harbor	0.00
Island	0.00
Jefferson	0.00
King	56.00
Kitsap	0.00
Kittitas	100.00
Klickitat	100.00
Lewis	54.79
Lincoln	100.00
Mason	0.00
Okanogan	100.00
Pacific	0.00
Pend Oreille	100.00
Pierce	40.84
San Juan	0.00
Skagit	51.70
Skamania	100.00
Snohomish	51.59
Spokane	100.00
Stevens	100.00
Thurston	0.00

Percentage of County Land Area with Medium or Higher Drought Exposure	
County	Percent County Area in Drought Hazard Zone
Wahkiakum	0.00
Walla Walla	100.00
Whatcom	66.97
Whitman	100.00
Yakima	100.00
Washington State	74.28

Population Exposure

Population exposure to drought hazard is estimated by overlaying the hazard layer (medium or higher rank) over the 2011 developed areas derived from the land cover database. The 2017 estimated population for all census tracts was allocated to respective urban areas and the overlap with hazard exposure is estimated using spatial analysis in Geographic Information System (GIS). A significant proportion of the State population (21 percent) resides in areas ranked at medium or higher exposure from droughts. The top three counties with the most number of residents in areas with medium or higher drought exposure include Spokane, Yakima and Benton. All census tracts in these counties -Grant, Franklin, Chelan, Walla Walla, Whitman, Kittitas, Stevens, Okanogan and Douglas – are also ranked medium or higher for drought risk. Cumulatively, these counties account for 20 percent of the estimated total State population. Less than 5 percent of the county population in Clark, Snohomish, Lewis, King and Pierce Counties reside in areas exposed to medium or higher drought hazard.

Population Exposure to Drought Hazard			
County	Total Population (2017 Estimates)	Percentage of Total State Population	Estimated County Population Exposed to Medium or Higher Drought Hazard (in % values)
Adams	19870	0.27	100.00
Asotin	22290	0.30	100.00
Benton	193500	2.65	100.00
Chelan	76830	1.05	100.00
Clallam	74240	1.02	0.00
Clark	471000	6.44	4.40
Columbia	4100	0.06	100.00
Cowlitz	105900	1.45	0.00
Douglas	41420	0.57	100.00
Ferry	7740	0.11	99.99
Franklin	90330	1.24	100.00

Population Exposure to Drought Hazard			
County	Total Population (2017 Estimates)	Percentage of Total State Population	Estimated County Population Exposed to Medium or Higher Drought Hazard (in % values)
Garfield	2200	0.03	100.00
Grant	95630	1.31	100.00
Grays Harbor	72970	1.00	0.00
Island	82790	1.13	0.00
Jefferson	31360	0.43	0.00
King	2153700	29.46	1.21
Kitsap	264300	3.62	0.00
Kittitas	44730	0.61	100.00
Klickitat	21660	0.30	100.00
Lewis	77440	1.06	1.62
Lincoln	10700	0.15	100.00
Mason	63190	0.86	0.00
Okanogan	42110	0.58	100.00
Pacific	21250	0.29	0.00
Pend Oreille	13370	0.18	100.00
Pierce	859400	11.76	0.55
San Juan	16510	0.23	0.00
Skagit	124100	1.70	9.22
Skamania	11690	0.16	100.00
Snohomish	789400	10.80	2.69
Spokane	499800	6.84	100.00
Stevens	44510	0.61	100.00
Thurston	276900	3.79	0.00
Wahkiakum	4030	0.06	0.00
Walla Walla	61400	0.84	100.00
Whatcom	216300	2.96	6.41
Whitman	48640	0.67	100.00
Yakima	253000	3.46	100.00
Washington State	7310300	100.00	21.07

Vulnerable Population Exposure

The social vulnerability index was created for each of the census tracts using American Community Survey (ACS) 2011-2016 5-year data. Social vulnerability data was first overlaid with developed areas extracted from the 2011 land cover database. Tract level social vulnerability estimates were assigned to respective developed areas in each of the tracts. This data was then overlaid with the hazard layer to identify socially vulnerable developed areas that overlap with medium or higher ranked hazard zones.

Overall, only 5 percent of the total population residing in urban areas ranked medium or higher on the social vulnerability index are also exposed to medium or higher risks from droughts. In Adams County, 100 percent of the population with medium or higher drought exposure is also ranked medium or higher on social vulnerability. In Yakima county, almost 50 percent of the population with medium or higher drought exposure is also ranked medium or higher on social vulnerability. Spokane County, with the highest population exposed to medium or higher droughts, has less than 5 percent of this population also ranked medium or higher on social vulnerability.

Vulnerable Population Exposure to Drought

County	Population (2017 Estimates)	Medium or Greater Drought Hazard Exposure	
		Estimated Vulnerable Population	As % of County Population
Adams	19870	19870	100.00
Asotin	22290	0	0.00
Benton	193500	12423	6.42
Chelan	76830	3014	3.92
Clallam	74240	0	0.00
Clark	471000	0	0.00
Columbia	4100	0	0.00
Cowlitz	105900	0	0.00
Douglas	41420	19986	48.25
Ferry	7740	0	0.00
Franklin	90330	38833	42.99
Garfield	2200	0	0.00
Grant	95630	33716	35.26
Grays Harbor	72970	0	0.00
Island	82790	0	0.00
Jefferson	31360	0	0.00
King	2153700	0	0.00
Kitsap	264300	0	0.00
Kittitas	44730	0	0.00
Klickitat	21660	0	0.00
Lewis	77440	426	0.55
Lincoln	10700	0	0.00
Mason	63190	0	0.00
Okanogan	42110	12227	29.03
Pacific	21250	0	0.00
Pend Oreille	13370	0	0.00
Pierce	859400	0	0.00
San Juan	16510	0	0.00
Skagit	124100	0	0.00
Skamania	11690	0	0.00
Snohomish	789400	37	0.00
Spokane	499800	18616	3.72
Stevens	44510	2750	6.18

Vulnerable Population Exposure to Drought			
County	Population (2017 Estimates)	Medium or Greater Drought Hazard Exposure	
		Estimated Vulnerable Population	As % of County Population
Thurston	276900	0	0.00
Walla Walla	61400	8452	13.77
Whitman	48640	7713	15.86
Washington State	7310300	342213	4.68

Built Environment

Drought does not pose any significant threat to the built environment. Therefore, no detailed assessment is included for this sector.

Critical Infrastructure

Drought does not pose any significant threat to the critical infrastructure facilities included in this risk analysis. Therefore, no detailed assessment is included for this sector.

State Facilities

Drought does not pose any significant direct threat to the State facilities. Therefore, no detailed assessment is included for this sector.

First Responders

Drought does not pose any significant threat to first responder facilities. Therefore, no detailed assessment is included for this sector.

Drought Risk Index (WaSRI-D)

The drought risk index (WaSRI-D) for each county is estimated as the average of the standardized rank of hazard exposure assessment for county area, population and vulnerable populations. The individual exposure assessment values were categorized into five classes (1: Low, 2: Medium-Low, 3: Medium, 4: Medium-High, and 5: High) using z-score transformation (standard deviations from the mean).

Classification Schema for Standardized Exposure Assessment Values	
Standard Deviation	Classification Rank
>1	High (5)
0.50 to 1.0	Medium-High (4)
0.5 to -0.5	Medium (3)
-0.5 to -1	Medium-Low (2)
< -1.0	Low (1)

The drought risk index (WaSRI-D) is the mean of these individual exposure rankings. While similar assessments were also done for economic consequences (described in the next sections), these specific rankings were not included in the estimation of the risk index. Economic consequence rankings were not included because of data quality limitations. Economic consequences estimates are based on overall county data. Including them in the index is likely to result in biased estimation of hazard risk. The natural environment impact assessment is limited to the environmental resources identified through national land cover dataset. Each natural hazard is associated with specific effects on the natural environment and therefore adoption of a common evaluation approach across all hazard types for environmental impacts is not appropriate.
Seven counties including Spokane, Benton, Yakima, Chelan, Grant, Franklin and Whitman Counties are ranked high for drought risk. Adams, Asotin, Douglas, Kittitas, Klickitat, Okanogan, Stevens and Walla Walla Counties are ranked medium-high for drought risk. The medium ranked counties include Columbia, Ferry, Garfield, King, Lincoln, Pend Oreille, Skagit, Skamania and Whatcom Counties. This group includes only two coastal counties.

Most of the counties with medium or higher risk from droughts are predominantly agricultural; therefore, the timing of the drought will be a significant factor in ultimate impacts on the State. Grant County, the leading agricultural county in terms of crop sales, and ranked 11th nationally by USDA in the 2012 Agricultural Census, is also at high risk from drought. Whitman County, the top wheat producing county in the nation is also estimated to be at high risk from droughts. Washington State Department of Agriculture provides detailed assessment of drought conditions and anticipated impacts on the agricultural productivity in Washington state (https://agr.wa.gov/pestfert/natresources/drought.aspx).

Drought Risk Index (WaSRI D) and Constituent Exposure Ranks for Each County

County	Area	Population	Vulnerable Population	Built Environment	Critical Infrastructure	State Facilities	First Responder Facilities	Drought Risk Index (WaSRI D)
Adams	Medium-High	Medium	Medium-High					MEDIUM
Asotin	Medium-High	Medium-High	Medium-High					MEDIUM-HIGH
Benton	Medium-High	High	Medium-High					HIGH
Chelan	Medium-High	High	Medium-High					HIGH
Clallam	Low	Low	Low					LOW
Clark	Medium-Low	Medium	Medium-Low					MEDIUM-LOW

Drought Risk Index (WaSRI D) and Constituent Exposure Ranks for Each County

County	Area	Population	Vulnerable Population	Built Environment	Critical Infrastructure	State Facilities	First Responder Facilities	Drought Risk Index (WaSRI D)
Columbia	Medium-High	Medium-Low	Medium-High					MEDIUM
Cowlitz	Low	Low	Low					LOW
Douglas	Medium-High	Medium-High	Medium-High					MEDIUM-HIGH
Ferry	Medium-High	Medium-Low	Medium					MEDIUM
Franklin	Medium-High	High	Medium-High					HIGH
Garfield	Medium-High	Medium-Low	Medium-High					MEDIUM
Grant	Medium-High	High	Medium-High					HIGH
Grays Harbor	Low	Low	Low					LOW
Island	Low	Low	Low					LOW
Jefferson	Low	Low	Low					LOW
King	Medium	Medium-High	Medium-Low					MEDIUM
Kitsap	Low	Low	Low					LOW
Kittitas	Medium-High	Medium-High	Medium-High					MEDIUM-HIGH
Klickitat	Medium-High	Medium-High	Medium-High					MEDIUM-HIGH
Lewis	Medium-Low	Medium-Low	Medium-Low					MEDIUM-LOW
Lincoln	Medium-High	Medium	Medium-High					MEDIUM
Mason	Low	Low	Low					LOW
Okanogan	Medium-High	Medium-High	Medium-High					MEDIUM-HIGH
Pacific	Low	Low	Low					LOW

Drought Risk Index (WaSRI D) and Constituent Exposure Ranks for Each County

County	Area	Population	Vulnerable Population	Built Environment	Critical Infrastructure	State Facilities	First Responder Facilities	Drought Risk Index (WaSRI D)
Pend Oreille	Medium-High	Medium	Medium-High					MEDIUM
Pierce	Medium-Low	Medium-Low	Medium-Low					MEDIUM-LOW
San Juan	Low	Low	Low					LOW
Skagit	Medium-Low	Medium	Medium					MEDIUM
Skamania	Medium-High	Medium	Medium-High					MEDIUM
Snohomish	Medium-Low	Medium	Medium-Low					MEDIUM-LOW
Spokane	Medium-High	High	Medium-High					HIGH
Stevens	Medium-High	Medium-High	Medium-High					MEDIUM-HIGH
Thurston	Low	Low	Low					LOW
Wahkiakum	Low	Low	Low					LOW
Walla Walla	Medium-High	High	Medium					MEDIUM-HIGH
Whatcom	Medium	Medium	Medium					MEDIUM
Whitman	Medium-High	Medium-High	High					HIGH
Yakima	Medium-High	High	High					HIGH

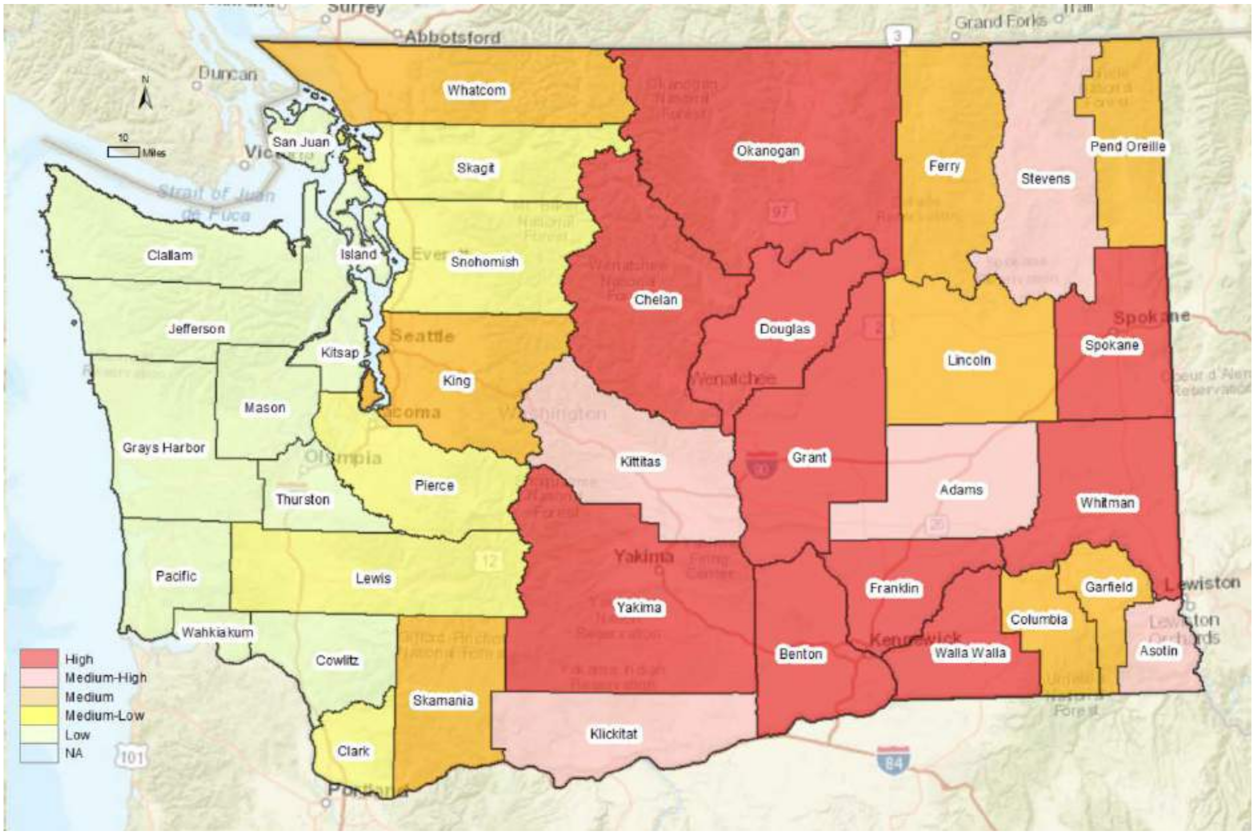

Figure D5: Drought Risk Index (WaSRI-D)

Economic Consequences

The economic activity data was derived from the National Association of Counties. This dataset provides the county level estimates of Gross Domestic Product (GDP) for 2016. The seven counties ranked high on the drought risk index contribute 13 percent of the State Gross Domestic Product (GDP). Counties ranked medium-high for drought risk contribute another 3 percent to the State GDP. Overall, counties ranked medium or higher on the drought risk index cumulatively account for 70 percent of the State GDP. This includes King County, by far the highest contributor to State GDP. The other two counties among the top three contributors to State GDP, Pierce and Snohomish Counties, both are ranked medium-low for drought risk. Most of the counties at high or medium-high risk from drought include key agricultural areas of the State. Therefore, prolonged periods of drought are likely to have a widespread impact on the local and regional economy. Severe drought conditions in these areas can also lead to significant national economic impacts. However, these indirect impacts down the agricultural production, distribution and consumption supply chain have not been included in this economic impact assessment.

Our changing climate will intensify drought implications for the State's economy.

Drought Risk (WaSRI D) and County GDP 2016		
County	Drought Risk Index (WaSRI D)	GDP 2016 (in Mil.)
Adams	MEDIUM	$746.07
Asotin	HIGH	$618.43
Benton	MEDIUM	$10,627.85
Chelan	HIGH	$4,363.01
Clallam	LOW	$2,573.06
Clark	LOW	$18,682.64
Columbia	LOW	$144.20
Cowlitz	MEDIUM	$4,474.88
Douglas	LOW	$1,037.39
Ferry	MEDIUM-HIGH	$198.13
Franklin	MEDIUM-HIGH	$3,356.16
Garfield	MEDIUM-LOW	$97.44
Grant	MEDIUM	$3,803.65
Grays Harbor	LOW	$2,237.44
Island	HIGH	$2,796.80
Jefferson	LOW	$867.23
King	MEDIUM	$230,344.61
Kitsap	MEDIUM-LOW	$12,082.18
Kittitas	LOW	$1,566.21
Klickitat	MEDIUM-LOW	$1,004.05
Lewis	MEDIUM	$2,573.06
Lincoln	MEDIUM-LOW	$347.25
Mason	HIGH	$1,566.21
Okanogan	MEDIUM-HIGH	$1,678.08
Pacific	LOW	$637.45
Pend Oreille	LOW	$354.63
Pierce	HIGH	$41,280.80
San Juan	MEDIUM	$602.88
Skagit	HIGH	$5,705.48
Skamania	HIGH	$218.04
Snohomish	MEDIUM	$39,378.97
Spokane	HIGH	$24,723.73
Stevens	MEDIUM	$1,111.56
Thurston	HIGH	$12,865.29
Wahkiakum	LOW	$93.41
Walla Walla	LOW	$2,908.67
Whatcom	LOW	$10,068.49
Whitman	MEDIUM	$2,237.44
Yakima	LOW	$10,404.10

Risk to Environment

Drought leads to water shortages and dry conditions which, if they persist for longer durations, can have long-term environmental impacts on local bio-diversity. It can result in changes in the local vegetation cover and displacement of sensitive species in the affected region. An important risk from drought is the increased susceptibility to wildfires.

To assess the risk to environmental resources, the spatial land cover mapped data was overlaid with the drought hazard layer (medium or higher ranked areas). Forests, scrubland, wetland and cropland areas were identified as ecologically critical areas. The overlap between these areas of ecological importance and drought hazard was analyzed through spatial analysis in GIS software. In Washington State, 31 percent of critical environment areas are also ranked medium or higher for droughts. Many of these regions include forested lands that are prone to wildfires during prolonged periods of dry weather. Additional, drought conditions can lead to short-term water availability and soil productivity. Persistent drought conditions for longer periods of times can result in significant threat to the local ecological diversity.

Environmentally Critical Areas

County	Percent of Critical Environmental Area in the county exposed to medium or higher drought risk
Adams	0.00
Asotin	0.00
Benton	0.00
Chelan	96.80
Clallam	22.73
Clark	33.79
Columbia	0.00
Cowlitz	28.97
Douglas	0.02
Ferry	0.00
Franklin	0.00
Garfield	0.00
Grant	0.00
Grays Harbor	0.00
Island	0.00
Jefferson	37.21
King	81.56
Kitsap	0.00
Kittitas	66.77
Klickitat	47.50
Lewis	50.83
Lincoln	0.00
Mason	13.16
Okanogan	48.38
Pacific	0.00
Pend Oreille	0.00
Pierce	68.07
San Juan	0.00
Skagit	62.66
Skamania	92.37

Environmentally Critical Areas	
County	Percent of Critical Environmental Area in the county exposed to medium or higher drought risk
Snohomish	73.88
Spokane	0.00
Stevens	0.00
Thurston	1.86
Wahkiakum	0.00
Walla Walla	0.00
Whatcom	65.31
Whitman	0.00
Yakima	51.60
Washington State	31.39

That exposure is increasing as the climate changes. Periods of drought are expected to increase stressing forests and their inhabitants, along with their drainages. Of considerable concern is the reduced periods where there is sufficient soil moisture during the summer to sustain the ecosystem. Many species will not be able to survive. Their death, in the case of plants, contributes to an increase in wildland fires. These fires are, and will continue, to have a compounding effect as fires create hydrophobic soils limiting the soil's ability to retain moisture, thereby causing a continuing cycle of additional fires and soil mobilization until the landscape becomes unproductive.

However, as with the damage cycle of disaster/rebuilding/disaster, this cycle too can be prevented through wise forest practices including fuel management, limited interface development and resource-based fire suppression practices.

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Earthquake Risk Summary

Washington State Risk Index for Earthquake (WaSRI-E)	**MEDIUM**
LIKELIHOOD	MEDIUM
Annual likelihood of a major earthquake event is 17%. According to the Pacific Northwest Seismic Network, there's a 10-20% chance of a Cascadia subduction zone earthquake in the next 50 years.	
HAZARD AREA	MEDIUM-LOW
25% of the State is exposed to medium or higher earthquake hazard.	
POPULATION	HIGH
76% of the State population is exposed to medium or higher earthquake hazard.	
VULNERABLE POPULATION	LOW
8% of total urban area in the state is both ranked medium or higher on social vulnerability and is also estimated to have medium or higher earthquake exposure.	
BUILT ENVIRONMENT	MEDIUM-HIGH
50% of the general building stock of the State is in areas with medium or higher exposure to earthquake hazard	
CRITICAL INFRASTRUCTURE	MEDIUM
46% of the facilities are in areas exposed to medium or higher earthquake hazard.	
STATE FACILITIES	MEDIUM-HIGH
64% of State-owned facilities are in areas exposed to medium or higher earthquake hazard. 71% of the State-leased facilities are in in areas exposed to medium or higher earthquake hazard.	
FIRST RESPONDERS	MEDIUM-HIGH
65% of the Fire Stations are in areas exposed to medium or higher earthquake hazard. 20% of the Law Enforcement facilities are in areas exposed to medium or higher earthquake hazard. 70% of the EMS facilities are in in areas exposed to medium or higher earthquake hazard.	
ECONOMIC CONSEQUENCES	HIGH
Counties ranked medium or higher on WaSRI-E account for 87.75 percent of real State GDP.	
ENVIRONMENTAL IMPACTS	MEDIUM-LOW
23% of critical environmental areas are in regions exposed to medium or higher earthquake hazard.	

Earthquake Hazard Profile

US Description

Due to its geologic setting, earthquakes occur nearly every day in Washington. Most are too small to be felt and do not cause damage. Large earthquakes are less common, but can cause significant damage to the things we count on in everyday life such as buildings, roads, bridges, dams and utilities. Overall, Washington has the second highest risk of economic loss from earthquakes in the U.S., only behind California.

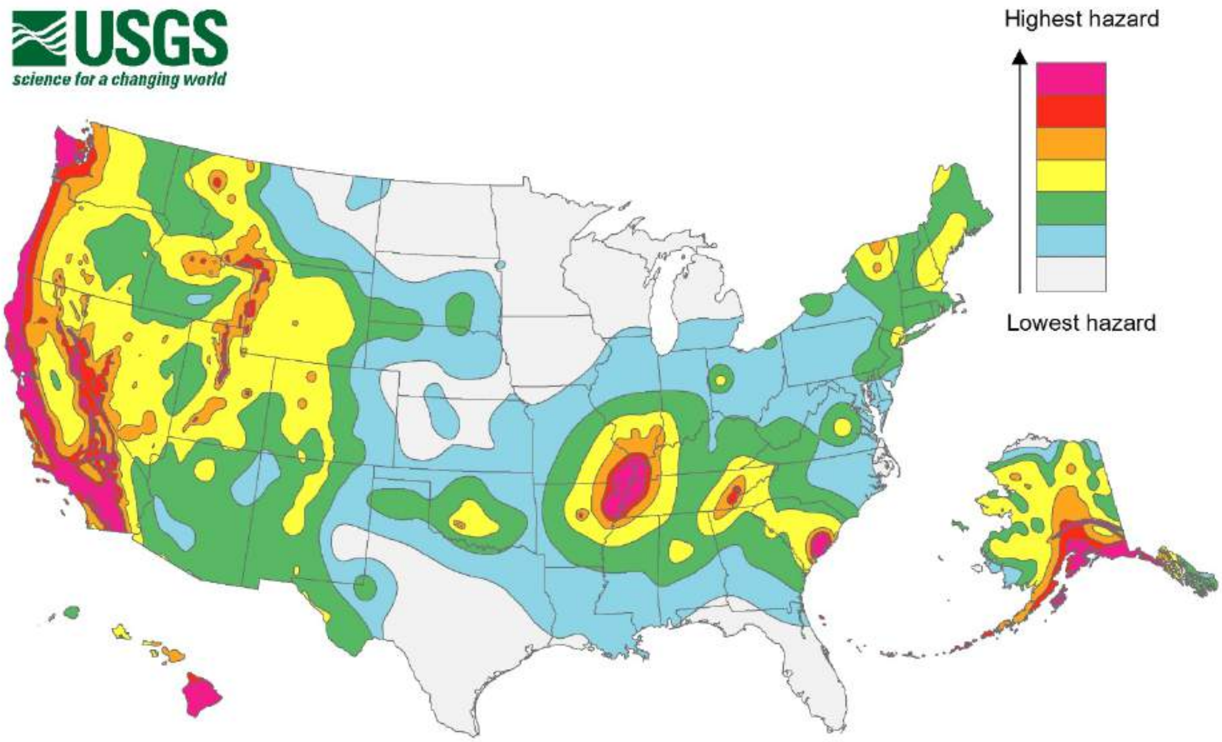


FIGURE E: NATIONAL SEISMIC HAZARD MAP, PGA 2% PROBABILITY OF EXCEEDANCE IN 50 YEARS (USGS, 2014)

An earthquake is shaking of the ground caused by a sudden slip on a fault. The sudden release of elastic energy stored in the rocks below the surface radiates as waves through the crust. The theory of plate tectonics provides the scientific basis for understanding earthquakes. According to this theory, the Earth’s lithosphere (the crust, and the more rigid part of the upper mantle) is made up of large sections called plates. Along with plate tectonics, there is also the idea of continental drift, that these pieces of lithosphere “float” pushed by currents in the Earth’s semi-solid mantle. The interactions between these plates – where they meet and where they diverge – are largely responsible for the seismic or earthquake activity on the planet.

Figure E1 shows the locations of the major tectonic plates, and the arrows indicate their relative directions of plate movement.

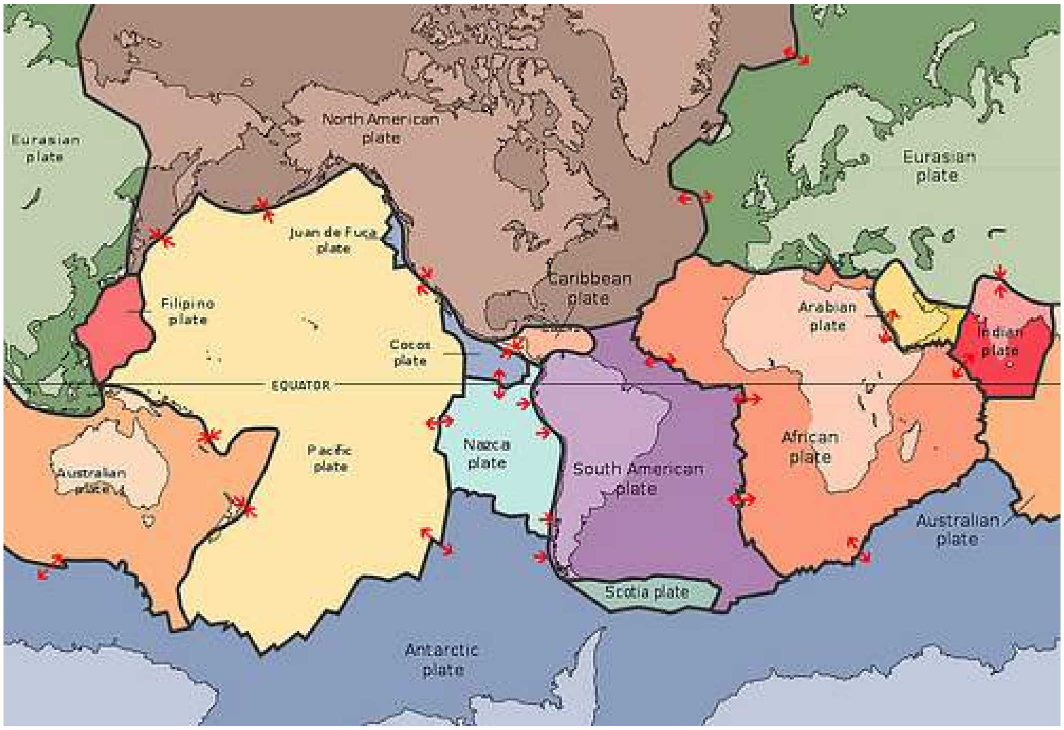


FIGURE E 1: MAJOR TECTONIC PLATES (SOURCE: USGS)

Faults are boundaries between two areas of rock that form in areas of high stress, for example where the motions of two lithosphere plates force them into one another. In these areas, extreme stress may cause the rock to break, forming a plane known as a fault. Once a fault has formed, the shearing resistance for continued movement of the fault is less than the shearing resistance required to fracture new intact rock. Thus, faults that have generated earthquakes in the recent past are likely to produce earthquakes in the future.

In the Pacific Northwest, movement of three tectonic plates drive our earthquake hazard. The Pacific Plate is moving to the Northwest at a speed of between 7 and 11 centimeters (cm) or ~3-4 inches a year. The North American plate is moving to the West-Southwest at about 2.3 cm (~1 inch) per year driven by the spreading center that created the Atlantic Ocean known as the Mid Atlantic Ridge. This may seem like small and slow motion, but over geologic time scales, these movements add up to hundreds and thousands of kilometers, and can reform parts of the surface of Earth. The small Juan De Fuca Plate is moving east-northeast at 4 cm (~1.6 inches) per year.

Once a part of a much larger oceanic plate called the Farallon Plate, the Juan de Fuca Plate is still actively subducting beneath North America. Its motion is not smooth, and can be considered a stick-slip fault whereby strain builds up over hundreds of years until the fault overcomes the force of friction and slips several tens of meters of the Juan De Fuca plate slide under the North American Plate suddenly, resulting in an earthquake. It takes a lot of slip (10s of meters) over a very large area to generate the M9 subduction zone earthquakes that shake our region every 200-600 years on average.

Earthquake Insurance in Washington

The hazard insurance market is challenging because typical homeowners' policies do not cover damage caused by floods or geologic hazards such as earthquakes. These must be purchased either separately or as an add-on to a homeowners' or renters' policy.

According to the OIC, which conducted a major earthquake insurance study in 2017, Washington's market has many insurers, and most of the insured properties are where the risk is greatest – west of the Cascades. Overall, residential coverage for the state is 11.3%, with Western Washington numbers much higher, 13.8% on average, compared with 1.7%.

Commercial coverage rates are much higher than residential, with 43.2% of insurance policies having some sort of earthquake coverage.
A key finding is that, for both residential and commercial customers, insured properties have a much higher assessed value than uninsured properties, indicating that it is higher-income people that are, in general, purchasing earthquake insurance coverage.
Thurston County has the highest rate of residential earthquake insurance coverage, at over 18%.

Earthquakes shake the ground because fault rupture releases vibrations that radiate in the form of seismic energy. These earthquake waves, also called body waves, come in two distinct forms: Primary or "P" waves and Secondary or "S" waves. When body waves reach the free surface of the earth some of their energy is converted into complex surface waves that are trapped near the surface of the Earth and produce generally lower frequency ground motions. P waves are compressional waves that do not produce much damage. They can move through any type of material and travel at almost twice the speed of S waves. S waves are shear waves that can often be seen on the ground surface and deform the ground perpendicular to their direction of travel. Unlike P waves, S waves are unable to pass through fluids such as water and magma. When S waves deform the ground, it causes lateral or shear (back and forth) forces on structures. Older buildings were constructed primarily to withstand gravity (vertical forces); therefore, they are more prone to fail due to the strong lateral motions experienced during a big earthquake.

Both P and S waves are generated across a broad spectrum of frequencies. The higher the frequency, the faster the energy from the earthquake attenuates, or dissipates, with distance. Also, due to this loss of energy or attenuation and geometrical spreading, locations close to the source of the rupture that caused the earthquake will receive more energy (and shaking) than more distant locations. When P and S waves arrive at the surface of the Earth, part of the energy is trapped and guided by the Earth's surface. Their behavior is different than for body waves, so they are identified as surface waves. These waves are classified into two types of surface waves - Love waves and Rayleigh waves. Rayleigh waves behave like ocean waves, with a rolling motion. They travel a little slower than Love waves. Love waves have horizontal back and forth motion that is perpendicular to the direction the wave is traveling.

Three Types of Earthquakes

Subduction Zone Earthquakes

The earth is covered with 10 major tectonic plates and many smaller plates. These plates shift in relation to one other. Some plates are pulling away or sliding past each other. Other plates come together with one plate slipping beneath the other in what is called a subduction zone. Strain builds up over time where the two plates grind against each other. Eventually, the jammed edge of one plate snaps upward in an enormous release of energy. Seismic waves radiate outward in prolonged earth shaking and numerous aftershocks. The uplift in the ocean floor at the fault generates tsunamis. The severe shaking can last 5 minutes or longer depending on the distance from the rupturing fault line, and can feel like an eternity to people experiencing the earthquake. The long seismic waves are a threat to tall buildings and long bridges. Large subduction zone earthquakes are the most powerful type of earthquake due to the amount of surface area involved when plates lock together and then rupture. The Cascadia subduction zone (CSZ) is 600 miles in length in up to 30 miles in width, the size of Ireland. The earthquake generated from an area this large is called a mega thrust event. A modern Northwest American city has not yet encountered a quake of this magnitude. The CSZ runs from Northern California up to British Columbia. This is where the Plate of Juan de Fuca dives beneath the North America Plate. A full description of the estimated impacts from a major CSZ rupture is included in the appendix to this document.

Wadati-**Benioff** *Deep Zone Earthquakes*

At the CSZ, the ocean floor is pushed down beneath the North America Plate. This activity generates both Benioff Earthquakes and feeds the volcanoes of the Cascade Mountain range. These earthquakes occur at depths of 15 to 60 miles beneath the surface. The largest earthquakes tend to occur at depths of 25 to 40 miles deep. Both the 1949 Olympia and the 2001 Nisqually quakes were deep earthquakes and measured M6.8 and lasted 20 seconds. There have been seven deep earthquakes in the Puget Sound region since 1870 that were M6 or higher. The recurrence interval is 30 to 50 years between events with a maximum size of M7+.

Largest Modern Earthquakes in Washington	
Location & Time	**Magnitude**
1872 Chelan	6.8
1909 Friday Harbor	6.0
1936 Walla Walla	6.1
1939 Bremerton	6.2
1949 Olympia	6.8
1965 Tacoma	6.7
2001 Nisqually	6.8

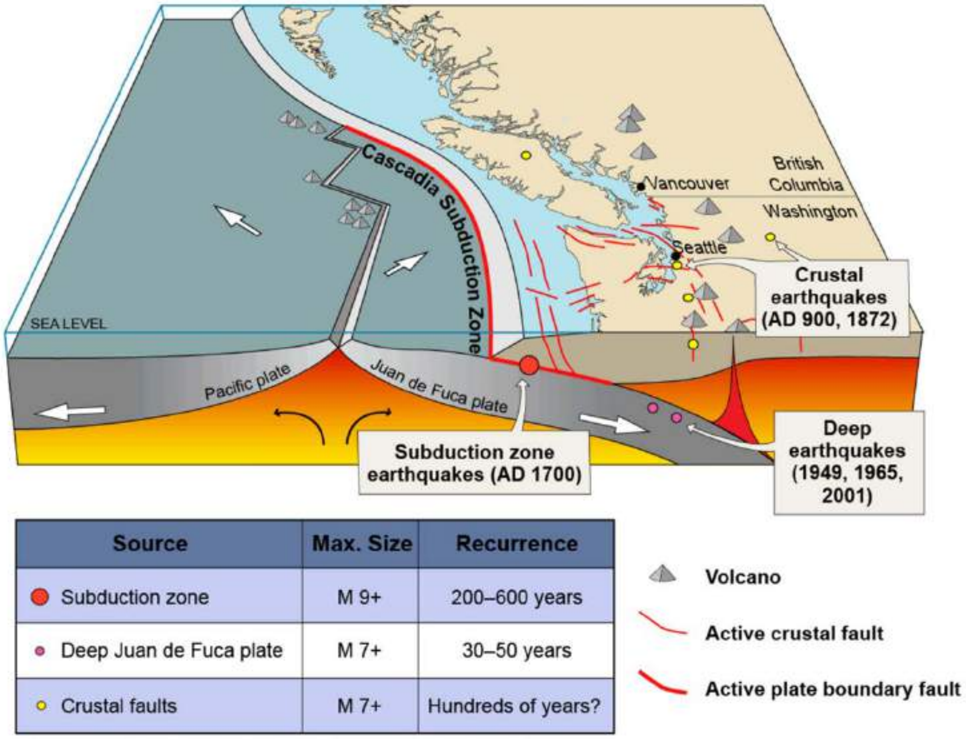
Source: USGS (2017)

Crustal Shallow Zone Earthquakes

Crustal earthquakes occur in the North America Plate at a depth of between 5 to 10 miles. These are also the most common types of earthquakes and result from stresses building up in the plate near the subduction zone. These earthquakes occur on both sides of the Cascade Mountain Range. However, the Puget Sound Region/Lowlands have the highest risk. Evidence has been found for large crustal earthquakes near Richland, Wenatchee and Yakima. Crustal earthquakes can reach a magnitude of 7.5 with numerous aftershocks. These earthquakes can be the most destructive to urban areas. The 1994 Northridge M6.7 and the 1995 Kobe M6.9 Earthquakes were crustal earthquakes that caused widespread destruction.

Earthquake Location, Extent, and Magnitude

The Cascadia region is likely to experience damaging earthquakes from three main sources: Cascadia Megathrust, Deep Intraplate and Crustal Fault earthquakes. The region also experiences volcanic earthquakes, which are generally too small to cause damage directly, but they provide strong clues about potential volcanic eruptions of Washington's five active volcanoes.



Source	Max. Size	Recurrence
● Subduction zone	M 9+	200–600 years
● Deep Juan de Fuca plate	M 7+	30–50 years
○ Crustal faults	M 7+	Hundreds of years?

*figure modified from USGS Cascadia earthquake graphics at http://geomaps.wr.usgs.gov/pacnw/pacnweq/index.html

Figure E 2: Sources of Washington Earthquakes

(Source: Washington state department of natural resources - https://www.dnr.wa.gov/programs-and-services/geology/geologic-hazards/earthquakes-and-faults#active-faults-and-future-earthquakes.)

Washington has dozens of active faults and fault zones. Figure E2 shows the general location of some past earthquakes in Washington. The term “active” can have different meanings. As per Washington Geological Survey,” active” means that a fault has evidence for movement within the Holocene time (since about 12,000 years ago and the retreat or our last continental glaciers). It usually also means that there are earthquakes (even small ones) on the fault. Some of these faults are in remote areas. Others, like the Seattle Fault and Southern Whidbey Island fault zone, cross under major cities and pose a significant hazard.

The largest active fault that will affect Washington (and the whole Pacific Northwest) is the Cascadia subduction zone. This fault produces some of the largest and most damaging earthquakes in the world (M9). A damaging earthquake is inevitable on this fault, but we do not know exactly when it will happen. The Seattle Fault last ruptured about 1,100 years ago in AD 900–950. Geologists do not yet know how often earthquakes happen on this fault. They do know that it is active and will likely produce a large M6–7.5 earthquake when it next ruptures. Washington State Department of Natural Resources has provided, using a FEMA generated risk computer model, Hazards-US (HAZUS), many possible earthquake event scenarios for many faults in the state. Figure E3 shows the locations of known active faults throughout the state of Washington. In general, longer faults can produce larger earthquakes.

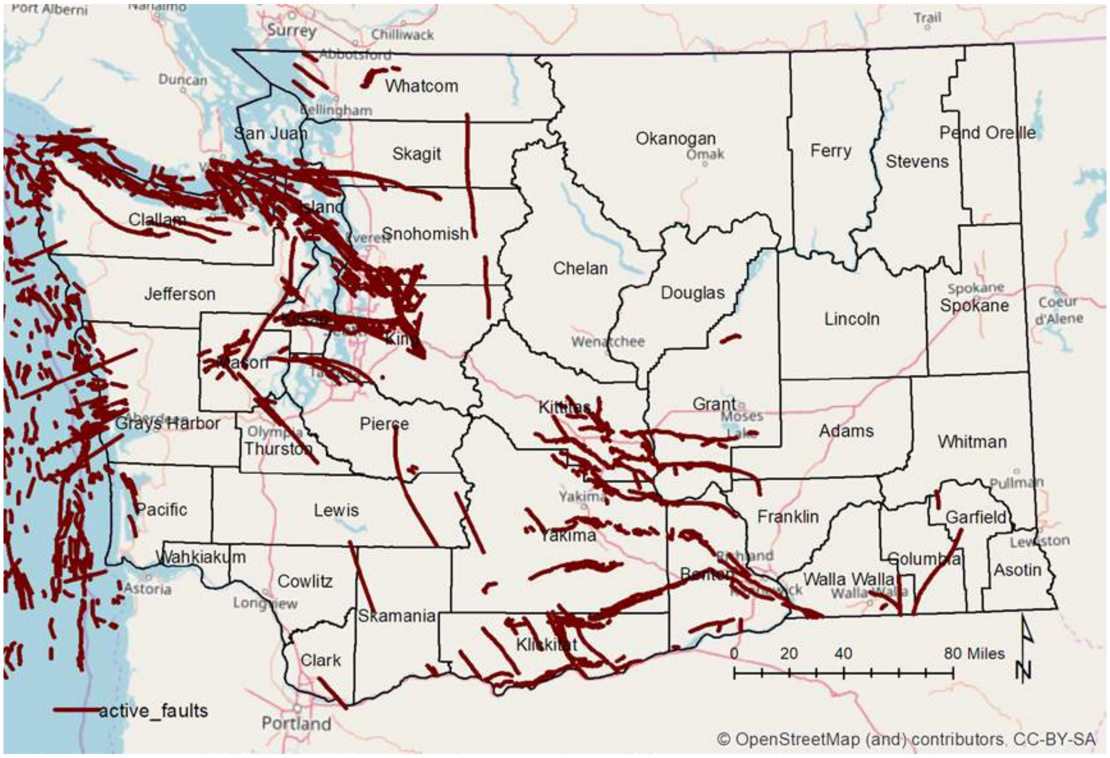
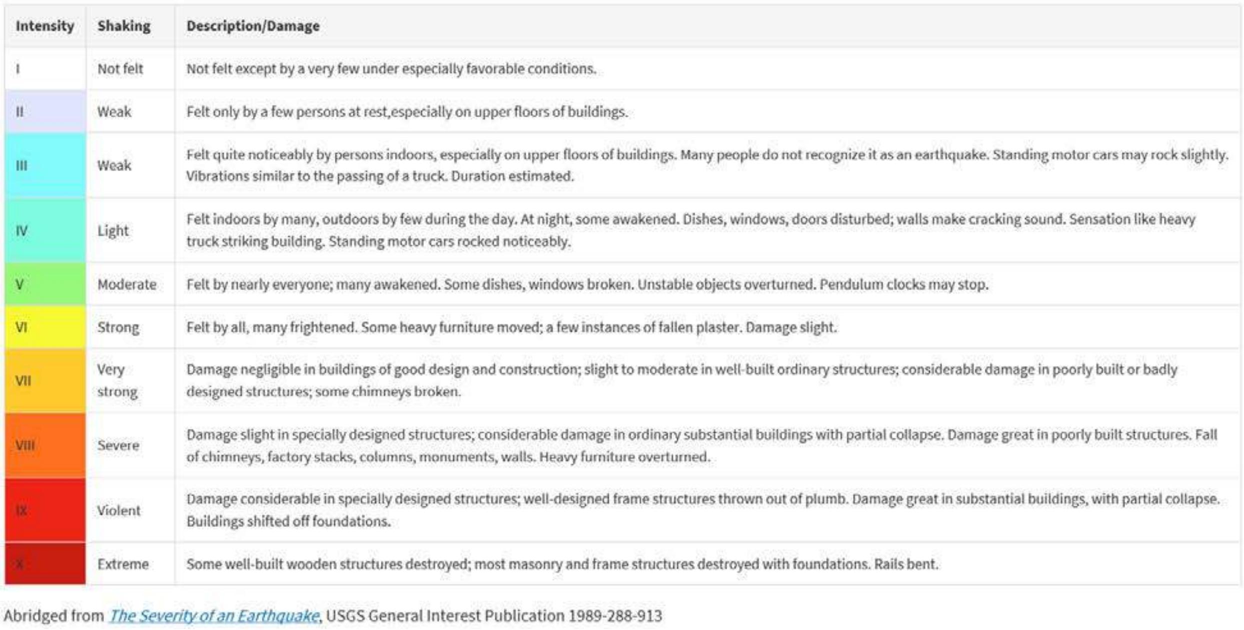


FIGURE E 3: ACTIVE EARTHQUAKE FAULTS IN WASHINGTON

The extent and magnitude of earthquakes are measured in two ways: Magnitude – measures the energy that is released at the earthquake source, and; Intensity – measures physical effects or how strongly it is experienced at a given location. Magnitude is calculated by seismologists from seismograph readings and is most useful to scientists comparing the power of earthquakes. Magnitude is often described using the Richter scale. An earthquake of Magnitude 2.5 or less is usually not felt. Typically, dishes rattling and china shaking occur at Magnitude 3.0, and magnitudes greater than 6.5 may cause extensive damage, when the earthquake strikes in or near a densely populated area.

The Modified Mercalli Intensity Scale is often used to measure intensity. It provides a subjective description of intensity and the physical effects of the shaking, based on observations at the event site. The damage from earthquake shaking is affected by several factors, such as distance from the epicenter and local geology and soils. On the Modified Mercalli Intensity Scale, a value of I is the least intense motion, and XII is the greatest ground shaking. Unlike magnitude, intensity can vary from place to place and is evaluated from people's reactions to events and the visible damage to man-made structures.



Intensity	Shaking	Description/Damage
I	Not felt	Not felt except by a very few under especially favorable conditions.
II	Weak	Felt only by a few persons at rest,especially on upper floors of buildings.
III	Weak	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
IV	Light	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	Moderate	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI	Strong	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII	Very strong	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
VIII	Severe	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX	Violent	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X	Extreme	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.

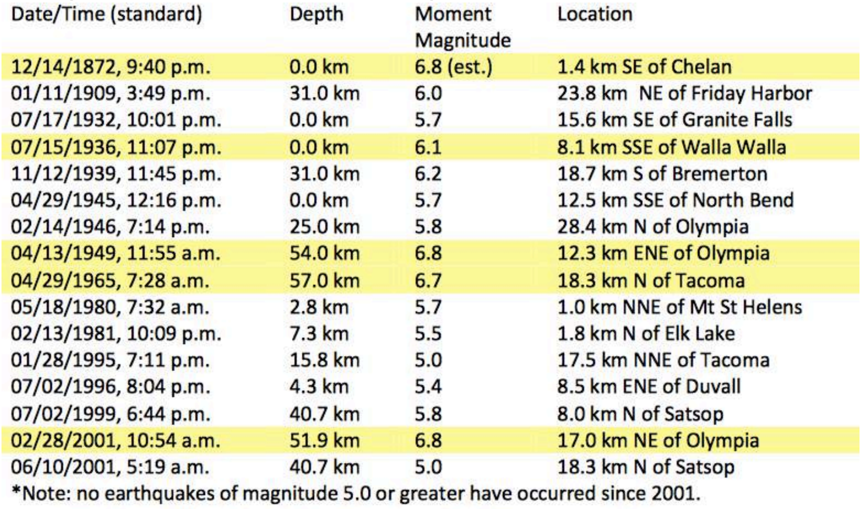
Abridged from *The Severity of an Earthquake*, USGS General Interest Publication 1989-288-913

Figure E 4: Modified Mercalli Intensity scale (Source: USGS)

It is important to note that MMI is a qualitative measure. While a great deal of useful data can quickly be gathered by untrained people with the qualitative MMI scale, engineers and others interested in designing earthquake-resistant structures need the quantitative information. A common such quantitative approach is to measure ground and spectral accelerations. This is often expressed as “peak ground acceleration” (PGA) expressed relative to the acceleration due to gravity (g) and determined by seismographic instruments. While Mercalli intensity and PGA are determined differently, they correlate reasonably well. PGA is measured as a percentage of the acceleration due to gravity (or percentage of g). PGA is not a measure of total energy but of how hard the ground shakes. To explain the measure of force, a vertical upwards PGA greater than 1.0 (100% g) would provide enough force to throw an object up into the air (i.e., provide acceleration higher than g to jump off the ground), but vertical PGAs this high are rare in earthquakes. PGA in the horizontal direction during earthquakes is often higher than vertical. The rapid shaking from earthquake waves is experienced by buildings and people as this rapidly accelerating in different directions. PGA of 10 – 30% g will cause mild to moderate damage. Over 30% g will cause significant damage in even well-designed buildings. Over 50% g can cause significant damage even in buildings designed to resist seismic forces. For more information of PGA visit: http://earthquake.usgs.gov/learn/glossary/.

Past Occurrences and Future Likelihood of Occurrence

Washington ranks second only to California for earthquake risk in the United States. There are thousands of earthquakes in Washington State every year, but most are too small to be felt. There have been 15 earthquakes greater than M5 since 1870 (figure E5).



Date/Time (standard)	Depth	Moment Magnitude	Location
12/14/1872, 9:40 p.m.	0.0 km	6.8 (est.)	1.4 km SE of Chelan
01/11/1909, 3:49 p.m.	31.0 km	6.0	23.8 km NE of Friday Harbor
07/17/1932, 10:01 p.m.	0.0 km	5.7	15.6 km SE of Granite Falls
07/15/1936, 11:07 p.m.	0.0 km	6.1	8.1 km SSE of Walla Walla
11/12/1939, 11:45 p.m.	31.0 km	6.2	18.7 km S of Bremerton
04/29/1945, 12:16 p.m.	0.0 km	5.7	12.5 km SSE of North Bend
02/14/1946, 7:14 p.m.	25.0 km	5.8	28.4 km N of Olympia
04/13/1949, 11:55 a.m.	54.0 km	6.8	12.3 km ENE of Olympia
04/29/1965, 7:28 a.m.	57.0 km	6.7	18.3 km N of Tacoma
05/18/1980, 7:32 a.m.	2.8 km	5.7	1.0 km NNE of Mt St Helens
02/13/1981, 10:09 p.m.	7.3 km	5.5	1.8 km N of Elk Lake
01/28/1995, 7:11 p.m.	15.8 km	5.0	17.5 km NNE of Tacoma
07/02/1996, 8:04 p.m.	4.3 km	5.4	8.5 km ENE of Duvall
07/02/1999, 6:44 p.m.	40.7 km	5.8	8.0 km N of Satsop
02/28/2001, 10:54 a.m.	51.9 km	6.8	17.0 km NE of Olympia
06/10/2001, 5:19 a.m.	40.7 km	5.0	18.3 km N of Satsop

*Note: no earthquakes of magnitude 5.0 or greater have occurred since 2001.

FIGURE E 5: SELECTED EARTHQUAKES OF MAGNITUDE 5 OR GREATER (HIGHLIGHTED ENTRIES DESCRIBED BELOW)

Most recently, the 2001 Nisqually earthquake was a M6.8 deep earthquake. That earthquake caused roughly $2 billion in property damage. The most damaged buildings were the historic unreinforced masonry (URM) buildings in places such as Pioneer Square.

According to Washington State Department of Natural Resources, over 1,000 earthquakes occur annually in the State. This is an average of approximately 3 per day though most go unfelt and do not cause damage. Larger magnitude earthquakes, which result in damage, occur less frequently in the state.

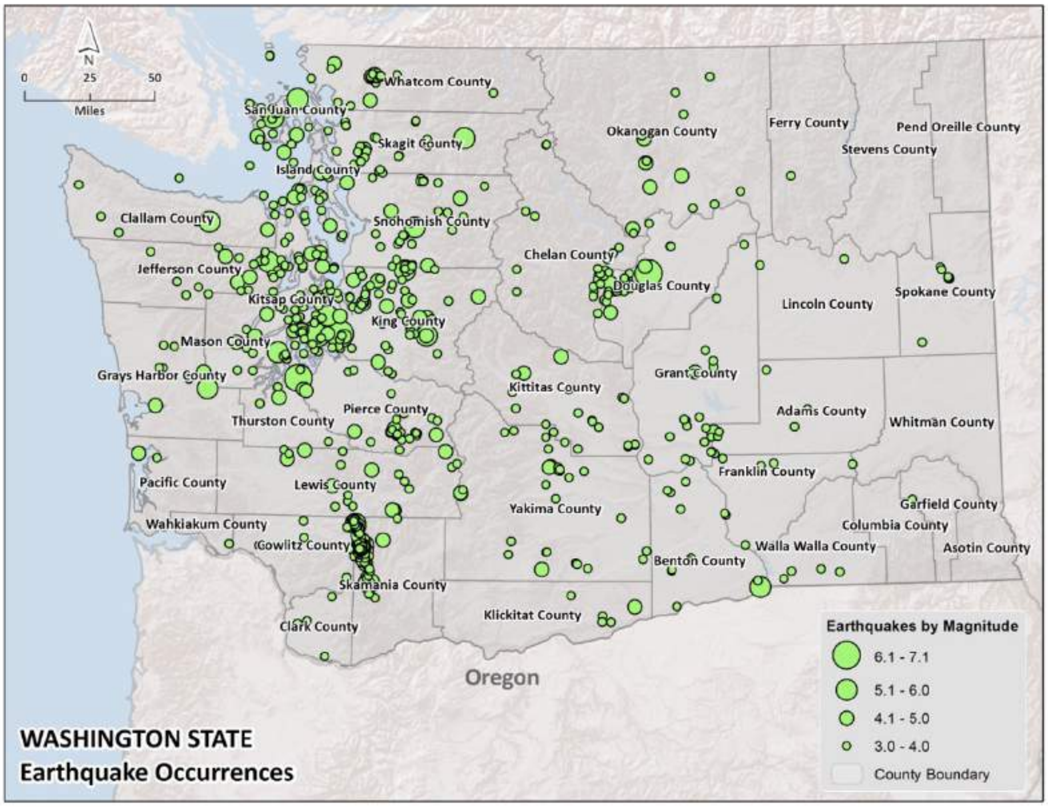


FIGURE E 6: HISTORIC EARTHQUAKE EPICENTERS WITH MAGNITUDES OF 3.0 OR GREATER, 1872-2011 (SOURCE: DNR)

Historical Earthquakes

Lake Chelan – December 14, 1872 (Source: Stover and Coffman, 1993)

The magnitude 6.8 (est.) earthquake occurred about 9:40 p.m. This earthquake was felt from British Columbia to Oregon and from the Pacific Ocean to Montana. The location for this earthquake was most likely northeast of the town of Chelan. Because there were few man-made structures in the epicenter area near Lake Chelan, most of the information available is about ground effects, including huge landslides, massive fissures in the ground, and a 27-foot high geyser.

Extensive landslides occurred in the slide-prone shorelines of the Columbia River. One massive slide, at Ribbon Cliff between Entiat and Winesap, blocked the Columbia River for several hours. Most of the ground fissures occurred in these areas: at the east end of Lake Chelan in the Indian camp; in the Chelan Landing-Chelan Falls area; on a mountain about 12 miles west of the Indian camp area; on the east side of the Columbia River (where three springs formed); and near the top of a ridge on a hogback on the east side of the Columbia River. These fissures formed in several locations. Slope failure, settlements, or slumping in water-saturated soils may have produced the fissures in areas on steep slopes or near bodies of water. Sulfurous water was emitted from the large fissures that formed in the Indian camp area. At Chelan Falls, "a great hole opened in the earth" from which water spouted as much as 27 feet in the air. The geyser activity continued for several days, and, after diminishing, left permanent springs.

Reports of structural damage are limited because of the epicenter's remote location. Heavy damage occurred to a log building near the mouth of the Wenatchee River. Ground shaking threw people to the floor, wave ripples were observed in the ground, and sounds like detonations were reported. About two miles above the Ribbon Cliff slide area, the logs on another cabin caved in.

Damaging ground shaking extended to the west throughout the Puget Sound basin and to the southeast beyond what is today the Hanford Site. Individuals in Idaho, Montana, Oregon, and Canada felt the earthquake. Aftershocks occurred in the area for two years.

State-Line Earthquake – July 15, 1936 (Sources: Neumann, 1936; Woodward-Clyde Consultants, 1980; Brown, 1937)

The earthquake, magnitude 6.1, occurred at 11:05 a.m. The epicenter was about 5 miles south-southeast of Walla Walla. It was widely felt through Oregon, Washington and northern Idaho, with the greatest shaking occurring in Northeast Oregon. Property damage was estimated at $100,000 (in 1936 dollars) in this sparsely populated area.

The earthquake moved small objects, rattled windows, and cracked plaster in the communities of Colfax, Hooper, Page, Pomeroy, Prescott, Touchet, Wallula, and Wheeler. However, most of the impact and damage was in the Walla Walla area. The earthquake alarmed residents of Walla Walla, many of whom fled their homes for the street. People reported hearing moderately loud rumbling immediately before the first shock. Standing pictures shook down, some movable objects changed positions, and doors partially opened. The earthquake was more noticeable on floors higher than the ground floor. It knocked down a few chimneys and many loose chimney brick; damaged a brick home used by the warden at the State Penitentiary that was condemned and declared unsafe; and damaged the local railroad station. Several homes moved an inch or less on their foundations, five miles southwest of Walla Walla, the quake restored the flow of a weakened 600-foot deep artesian well to close to original strength; the flow had not diminished after several months. Walla Walla residents reported about 15 - 20 aftershocks.

Olympia Earthquake – April 13, 1949 (Sources: Noson, Qamar, Thorson, 1988; Stover and Coffman, 1993)

The earthquake, magnitude 6.8, occurred at 11:55 a.m. The epicenter was about eight miles north-northeast of Olympia, along the southern edge of Puget Sound. Property damage in Olympia, Seattle, and Tacoma was estimated at $25 million (in 1949 dollars); eight people were killed, and many were injured.

School buildings in distant towns were seriously damaged. Thirty schools serving 10,000 students were damaged; 10 were condemned and permanently closed. Chimneys on more than 10,000 homes required repair. Water spouted from cracks that formed in the ground at Centralia, Longview, and Seattle. One new spring developed on a farm at Forest. Ground water, released by the shaking, flooded several blocks of Puyallup. Downed chimneys and walls were reported in towns throughout the area.

In Olympia, damage was primarily confined to the old part of the city and to areas of the port built on artificial fill. Most large buildings were damaged, including eight structures on the Capitol grounds. Many chimneys and two large smokestacks fell. Public utilities sustained serious damage; water and gas mains were broken, and electric and telegraph services were interrupted. Breaks in 24 water mains temporarily closed the downtown business district.

In Centralia, the earthquake damaged 40 percent of the homes and businesses; two schools and a church were condemned; and the city's gravity-feed water system badly damaged. In Chehalis, damage occurred to four schools, city hall, the library, and county court house; the library was condemned. Seventy-five percent of the chimneys had to be replaced.

In Seattle, houses on filled ground were demolished, many old brick buildings were damaged, and chimneys toppled. One wooden water tank and the top of a radio tower collapsed. A 60-inch main broke at the city's water reservoir. Power failures occurred when swinging transmission lines touched, causing circuit breakers to trip. The gas distribution system broke at nearly 100 points, primarily due to damage caused by ground failure.

In Tacoma, many chimneys of older structures were knocked to the ground and many buildings were damaged. Water mains broke from landslides and settling in the tide flats. Transformers at the Bonneville Power Administration substation were thrown out of alignment. A huge section of a 200-foot cliff toppled into Puget Sound three days after the earthquake, and produced a tsunami that swept across Tacoma Narrows and reflected to Tacoma, flooding a group of houses along the shoreline railroad bridges were thrown out of alignment. A 23-ton cable saddle was thrown from the top of a Tacoma Narrows bridge tower, causing considerable damage.

The earthquake was also felt in Idaho, Montana, Oregon, and in British Columbia, Canada.

Seattle-Tacoma Earthquake – April 29, 1965 (Sources: Stover and Coffman, 1993; Noson, Qamar, Thorson, 1988)

The earthquake, magnitude 6.7, struck the Puget Sound area at 7:28 a.m. The epicenter was about 12 miles north of Tacoma at a depth of about 40 miles. The earthquake caused about $12.5 million (in 1965 dollars) in property damage and killed seven people.

A rather large area of ground shaking in Seattle and its suburbs, including Issaquah, characterized the quake. Pockets of intense ground shaking, seen in damage such as fallen chimneys, were associated with variations in the local geology. In general, damage patterns repeated those observed in the April 1949 earthquake, although that event was more destructive. Many buildings damaged in 1949 sustained additional damage in 1965.

Most damage in Seattle was concentrated in areas of filled ground, including Pioneer Square and the waterfront, which both contain many older masonry buildings; nearly every waterfront building experienced damage. Eight schools serving 8,800 students were closed temporarily until safety inspections could be completed; two schools were severely damaged. Extensive chimney damage occurred in West Seattle. The low-lying and filled areas along the Duwamish River and its mouth settled, causing severe damage at Harbor Island; slumping occurred along a steep slope near Admiral Way. A brick garage partly collapsed at Issaquah; one school was damaged extensively; and chimneys in the area sustained heavy damage. Many instances of parapet and gable failure occurred. Damage to utilities in the area was not severe as in 1949.

Also damaged were two electric transmission towers in a Bonneville Power Administration substation near Everett; the towers each supported 230,000-volt lines carrying power from Chief Joseph Dam to the substation. Three water mains failed in Seattle, and two of three 48-inch water supply lines broke in Everett.

Buildings with unreinforced brick-bearing walls with sand-lime mortar were damaged most severely. Multistory buildings generally had slight or no damage. However, the Legislative Building once again was damaged and temporarily closed; government activities moved to nearby motels. Performance of wood frame dwellings was excellent, with damage confined mainly to cracks in plaster or to failure of unreinforced brick chimneys near the roofline.

The earthquake was also felt in Idaho, Montana, Oregon, and in British Columbia, Canada.

Nisqually Earthquake – February 28, 2001 (Sources: FEMA, 2001; University of Washington, 2001)

The earthquake, magnitude 6.8, struck the Puget Sound area at 10:54 a.m. The epicenter was below Anderson Island near the Nisqually River delta in Puget Sound about 50 miles south of Seattle and 11 miles northeast of Olympia. Ground shaking lasted about 20 seconds. Two minor aftershocks occurred near the epicenter of the main shock. This event was a slab earthquake; its depth calculated at 32 miles below the earth’s surface in the Juan de Fuca plate.

The area of most intense ground shaking occurred along the heavily populated north-south Interstate 5 corridor, not around the epicenter. This was due to the amplification of the earthquake waves on softer river valley sediments. The earthquake was felt over a large area – from Vancouver, British Columbia, to the north; to Portland, Oregon, to the south; and Salt Lake City, Utah, to the southeast.

The six counties most severely damaged by the earthquake – King, Kitsap, Lewis, Mason, Pierce, and Thurston – were declared federal disaster areas one day after the event. Eventually, 24 counties received disaster declarations for Stafford Act assistance under Federal Disaster #1361. Stafford Act disaster assistance provided was $155.9 million. Small Business Administration disaster loans approved - $84.3 million. Federal Highway Administration emergency relief provided to date - $93.8 million.

Various estimates have placed damage to public, business and household property caused by the Nisqually earthquake at from $1 billion to $4 billion. A 2002 study by the University of Washington funded by the National Science Foundation estimated the quake caused $1.5 billion in damages to nearly 300,000 households. The study indicates that structural damage to roofs, walls and foundations accounted for nearly two-thirds of losses, followed by chimney damage, and damages to nonstructural elements and household contents. A second study, also by the University of Washington and funded by the Economic Development Administration of the U.S. Department of Commerce, estimated that 20 percent of small businesses in the region affected by the quake had a direct physical loss and 60 percent experienced productivity disruptions.

Severe damage occurred in Olympia, at SeaTac Airport, and in south Seattle in the Pioneer Square and SODO areas. Structures damaged included office buildings, residences, schools, hospitals, airport facilities and churches. Many damaged structures and surrounding areas were closed for various lengths of time following the earthquake.

Structural damage was primarily concentrated in older, unreinforced masonry buildings built before 1950, with some damage reported to wood-frame structures and reinforced concrete structures. In general, new buildings and buildings that had recently been seismically upgraded typically displayed good structural performance, but many still sustained non-structural damage.

In the major urban areas of King, Pierce and Thurston counties, 1,000 buildings were rapidly assessed immediately following the earthquake. Of these, 48 buildings were red-tagged, indicating serious damage, and 234 were yellow-tagged indicating moderate damage.

Damaged significantly were several state government buildings in Olympia, including the Legislative Building (the state’s Capitol Building). The dome of the 74-year-old building sustained a deep crack in its limestone exterior and damage to supporting columns. There was non-structural damage which occurred throughout the building. Most other state agency buildings closed for one or more days for inspection and repair.

Lifeline systems generally performed well during the event. Water utilities reported minor structural damages; many wells in Eastern Washington reportedly went dry. A gas-line leak caused a fire and explosion when two maintenance workers were resetting an earthquake valve at a correctional facility near Olympia. Seattle City Light reported 17,000 customer power outages, and Puget Sound Energy reported 200,000 customers without power, but power was restored to most customers within a day. The volume of calls placed immediately after the earthquake overloaded landline and wireless communication systems.

Transportation systems also suffered damage. Seattle-Tacoma International Airport closed immediately because its control tower was disabled. A temporary backup control tower allowed reopening of the airport to limited traffic several hours after the quake. King County Airport (Boeing Field) suffered serious cracking and gaps on the runway due to soil liquefaction and lateral spreading. The main runway reopened for business a week later.

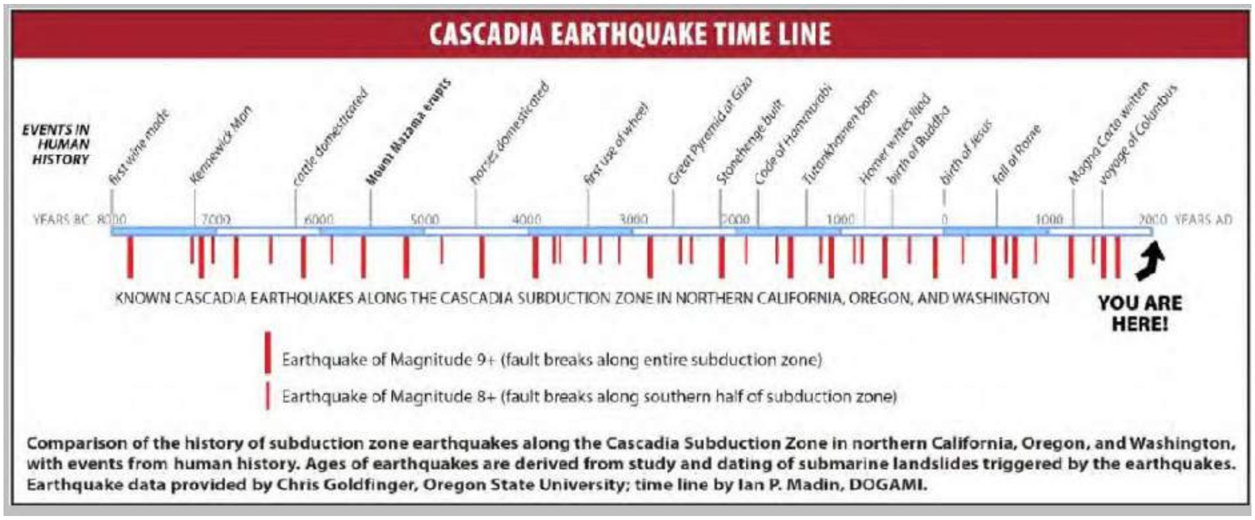
While the area’s overall road network remained functional, many highways, roads, and bridges were damaged. Several state routes and local roadways closed due to slumping and pavement fractures. The quake badly damaged the Alaskan Way Viaduct (State Route 99), a major arterial in Seattle. Temporary repairs made the structure usable; various proposals to permanently repair or replace it run in the billions of dollars. Two local bridges closed due to significant damage – the Magnolia Bridge in Seattle and the Fourth Avenue Bridge in Olympia. There was minor damage to dock facilities in both Tacoma and Seattle, but not extensive enough to interrupt commercial port services.

The state's dams fared well during the earthquake. Of the 290 dams inspected by state engineers, only five had earthquake-related damage; these dams were susceptible to damage due to their poor construction and weak foundations. Dams controlled or regulated by the Federal Energy Regulatory Commission, the Bureau of Reclamation, or the U.S. Army Corps of Engineers, were not damaged.

Future Probability of Occurrence

It is impossible to forecast earthquakes given our existing technology, but scientists can estimate general probability based on historic occurrences and location among other factors. The size of a fault segment, the stiffness of rocks, and the amount of accumulated strain combine to control the magnitude and timing of earthquakes. Fault segments likely to break can be identified where faults and plate motions are well known. If a fault segment is known to have broken in a past earthquake, recurrence time and potential magnitude and impacts of a future earthquake can be estimated.

Scientists currently estimate that a magnitude 9 earthquake in the Cascadia subduction zone occurs about once every 200-600 years. The last one was in 1700. Investigations have identified 41 Cascadia subduction zone interface earthquakes over the past 10,000 years, which corresponds to one earthquake about every 250 years. Of these 41 earthquakes, about half are M9.0 or greater earthquakes that represent full rupture of the fault zone from Northern California to British Columbia. The other half of the earthquakes represents M8+ earthquakes that rupture only the southern portion of the subduction zone. The 300+ years since the last major Cascadia subduction zone earthquake is longer than the average of about 250 years for M8 or greater and shorter than some of the intervals between M9.0 earthquakes. The time history of these major earthquakes is shown below.



Comparison of the history of subduction zone earthquakes along the Cascadia Subduction Zone in northern California, Oregon, and Washington, with events from human history. Ages of earthquakes are derived from study and dating of submarine landslides triggered by the earthquakes. Earthquake data provided by Chris Goldfinger, Oregon State University; time line by Ian P. Madin, DOGAMI.

FIGURE E 7: CASCADIA EARTHQUAKE TIMELINE (SOURCE: OREGON RESILIENCE PLAN)

Scientists currently estimate the probability of future occurrence for deep earthquakes like the 1965 magnitude 6.5 Seattle-Tacoma event and the 2001 magnitude 6.8 Nisqually event is about once every 35 years. The USGS has estimated that there is an 84% chance of a magnitude 6.5 or greater deep earthquake over the next 50 years.

Relationship with Other Hazards

Ground motion from an earthquake can initiate many other natural and man-made hazards. Two common natural hazards that can be initiated by a seismic event include avalanches and landslides. Earthquakes off the coast can also generate tsunamis.

A tsunami is a series of waves generated in a body of water by a disturbance that moves the whole water column extending from the ocean floor to the water surface. Tsunamis can impact coastlines, causing devastating property damage and loss of life. The Cascadia subduction zone (CSZ) produces great (>M8) earthquakes and has produced large tsunamis that impacted the coasts of British Columbia, Washington, Oregon, and Northern California. The average reoccurrence interval for these great earthquakes is between 200 and 600 years. Most, perhaps all, of these CSZ earthquakes produced tsunami waves. The last great earthquake here occurred on January 26, 1700 and produced a tsunami that took lives in this region and across the Pacific along the coast of Japan and elsewhere.

Dams, levees, and canals are also at risk of damage that could be caused by an earthquake or the resulting seiches. These damages have the possibility of causing the structures to fail, thereby producing a dam/levee/canal failure hazard event. Earthquakes can cause significant damages to critical infrastructure systems including communication, transportation, and other lifeline systems. Uplift and displacement from a major seismic event could also result in the re-routing of existing streams, potentially causing flooding. The damages that result from an earthquake can also initiate fires that can further cause significant harm to life and property.

The damages associated with an earthquake are influenced by four key variables: the nature of the seismic activity; the composition of the underlying geology and soils; the level and quality of development of the area struck by the earthquake; and the time of day. The properties of the seismic activity include distribution (localized or widespread), depth of release and type of seismic waves generated influences the nature, and location of damage. Shallow quakes will hit the area close to the epicenter harder but tend to be felt across a smaller region than deep earthquakes. The surface geology and soils of an area influence the propagation of seismic waves and how strongly the energy is felt. Generally, stable areas (e.g., solid bedrock) experience less destructive shaking than unstable areas (e.g., fill soils).

The location of a community or even individual buildings plays a strong role in the nature and extent of damage from an event. A small earthquake in the center of a major city can have far greater consequences than a major event in a thinly populated place. The time of day that an event occurs controls the distribution of the population in an affected area. On work days, most of the community will transition between work or school and home; therefore, the location of the population with respect to the location of the seismic event will influence the resulting impacts.

Earthquake Risk Assessment

Earthquake Hazard

Earthquake hazard estimates are based on two key variables.

First, are the intensity estimates in peak ground acceleration (PGA) values as derived from U.S. Geological Survey nationwide probabilistic earthquake hazard data (figure E8). Hazard values are the maximum peak ground acceleration (defined in preceding section) associated with a 2500-year probabilistic earthquake, i.e. at 2% exceedance in 50 years (Peterson et al. 2011). The seismic hazard map incorporates multiple sources of earthquakes to predict the overall earthquake hazard for the State.

The map shows significantly higher ground motions on the western part of the State. This highlights the greater influence of specific sources on probabilistic ground motions in west such as the Cascadia Subduction

Zone earthquakes resulting in highest values on the west coast and then north-south bands that cross the entire State. High PGA values are also evident on the Southern Whidbey Island Fault and the Seattle Fault.

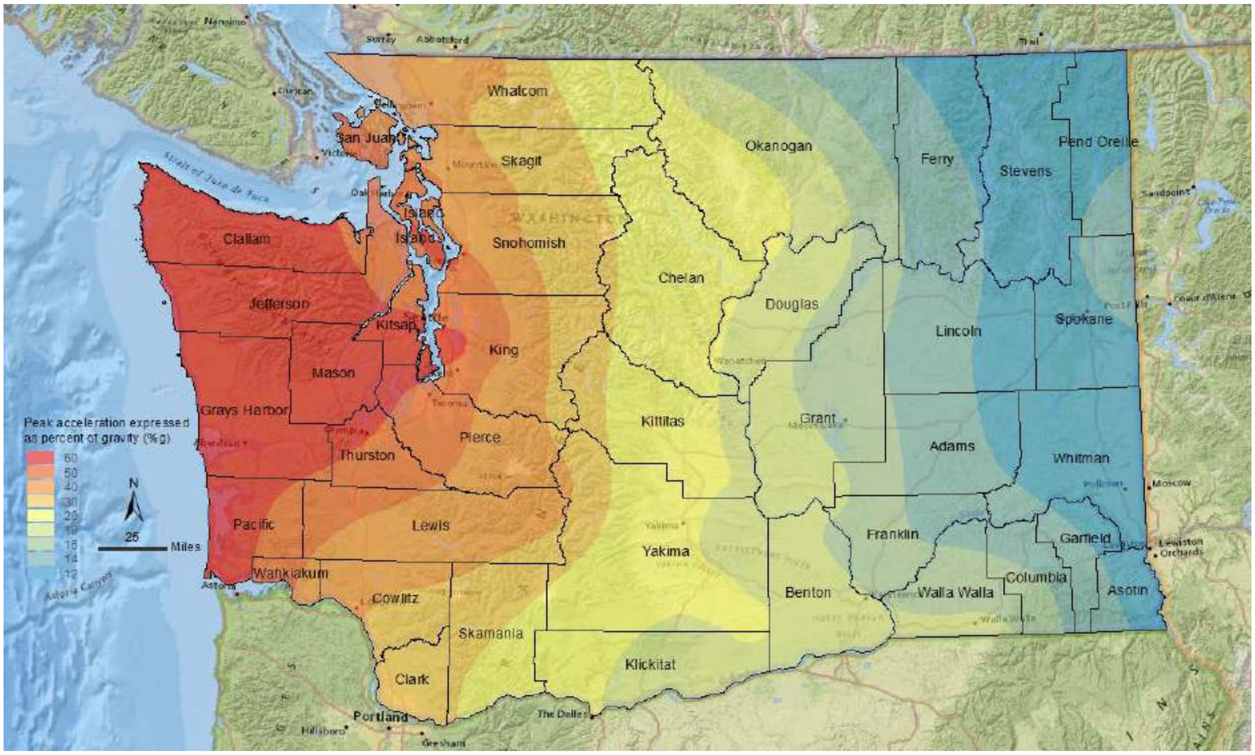


FIGURE E 8: USGS MAXIMUM PEAK GROUND ACCELERATION FOR A 2500-YEAR PROBABILISTIC EARTHQUAKE

The PGA values were converted into a five-item scale as shown in table below.

Reclassification of PGA values into 5 item Hazard Scale	
Original PGA Value	Reclassified Hazard Rank
0-12	1
13-24	2
25-36	3
37-48	4
49-60	5

Given the multiple seismic sources of earthquakes in Washington, probabilistic seismic hazard maps based on multiple seismic sources (as shown in figure E 8 above) are considered the most appropriate tool for risk analysis, increasing public awareness, and hazard mitigation planning. In contrast, deterministic earthquake scenarios based on existing nature of seismic sources are often used to determine worst case outcomes to supplement emergency planning and preparedness efforts. Washington State Department of Natural Resources has developed a suite of 20 such deterministic earthquake models for important faults, and associated plausible magnitudes based on past geological studies. A summary of these modelling results is provided in Appendix E 1.

The second variable is derived from the relative liquefaction potential assessment for Washington State done by Palmer and colleagues (2004). This data is part of Washington State DNR geodatabase that contains statewide ground response data for Washington. Liquefaction is a natural phenomenon in which saturated, sandy soils lose their strength and behave like a liquid. Liquefaction is caused by severe ground shaking of these wet soils during earthquake events. In this research study, Palmer and colleagues have classified various regions in the State of Washington as having 'very low' to 'high' relative liquefaction susceptibility (figure E5).

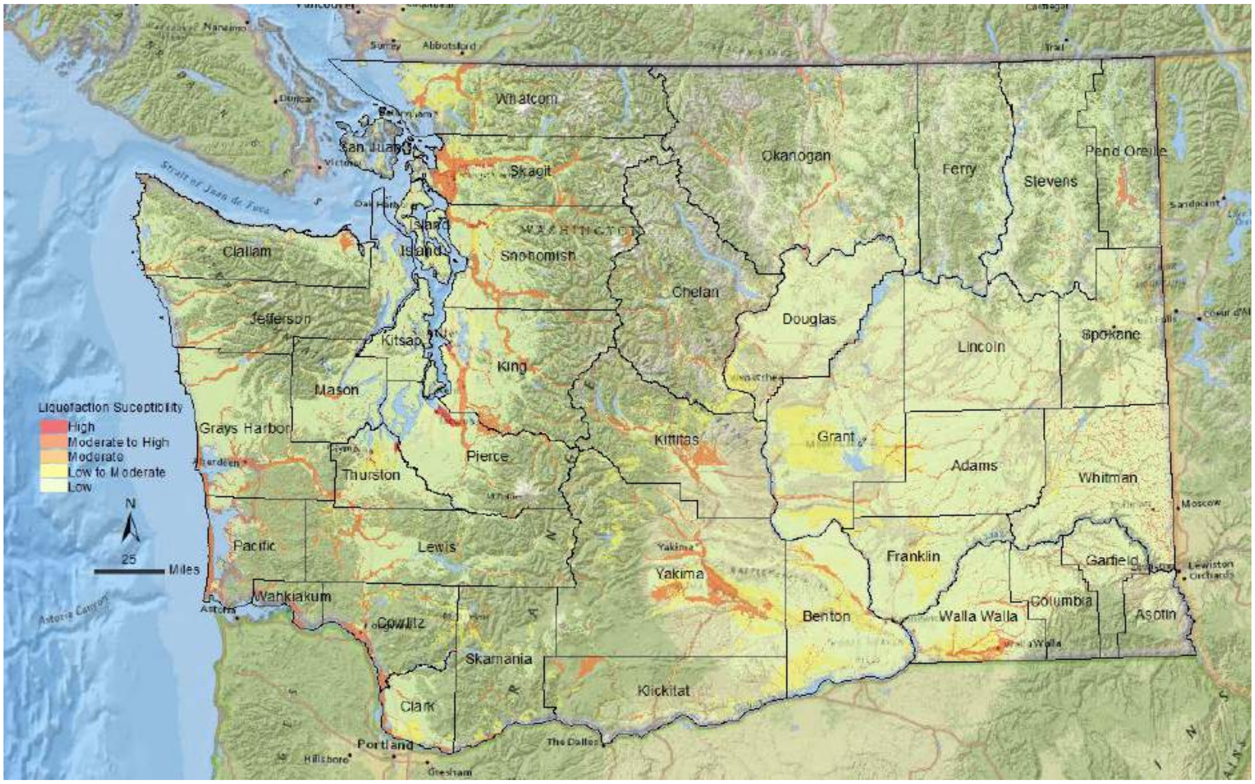


FIGURE E 9: RELATIVE LIQUEFACTION POTENTIAL

Liquefaction susceptibility assessments were converted into a five-point hazard as per the schema presented in table below:

Reclassification of Liquefaction Susceptibility into five item Hazard Scale	
Original Liquefaction Susceptibility Values	Reclassified Hazard Rank
High	5
Moderate to High	4
Moderate	3
Low to Moderate	2
Low	1
Very Low to Low	1
Very Low	1
N/A	0

The two variables were combined in to a single measure of earthquake hazard using additive spatial overlay analysis in GIS. The two reclassified hazard layers were overlaid, and the individual hazard values were added for each pixel to create a cumulative earthquake hazard rank (Figure E7).

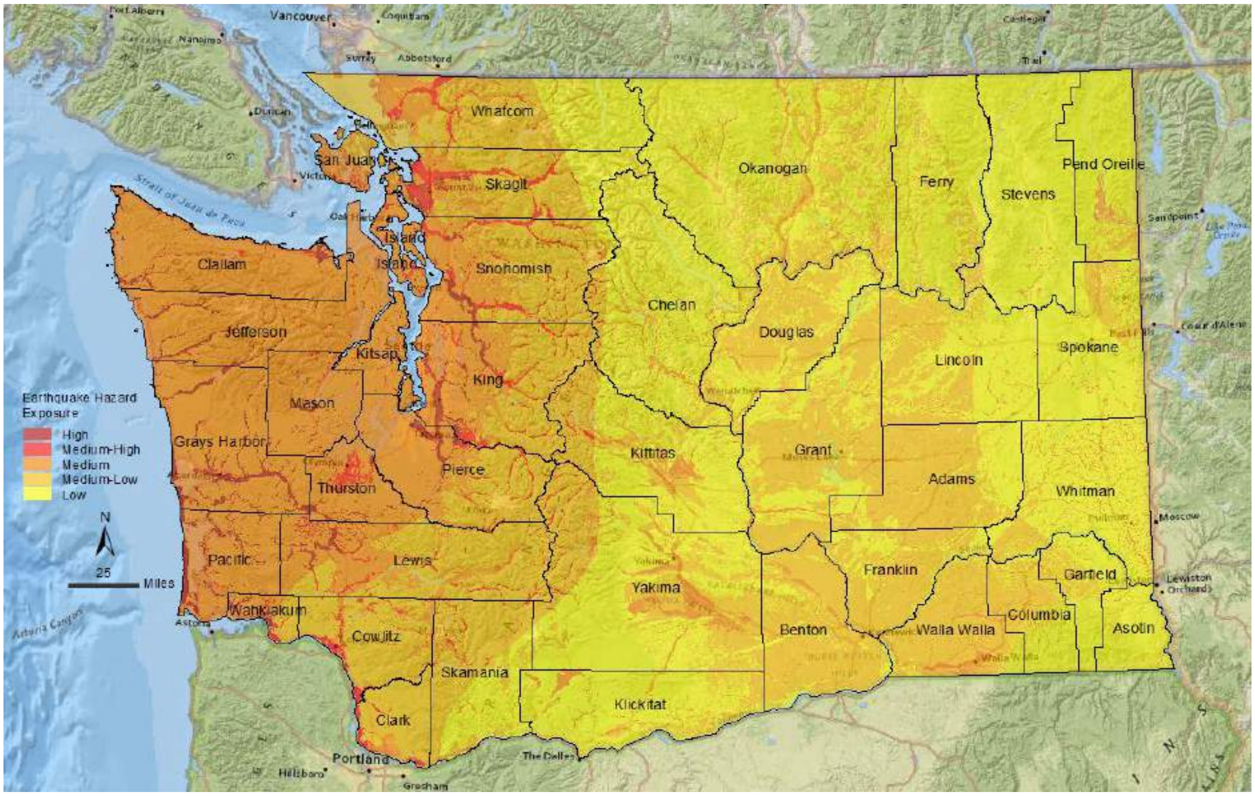


FIGURE E 10: ESTIMATED EARTHQUAKE HAZARD IN WASHINGTON

Area Exposure

Overall, 25.48 percent of the total land area of the state is estimated to be at medium or higher (ranked medium, medium-high, and high) exposure from earthquake hazards. Only, 1.42 percent of the area is ranked high, 1.69 percent is ranked medium-high, and 22.36 percent is ranked as medium for earthquake exposure. In comparison, almost 40 percent of the land area in 15 coastal shoreline counties is ranked at medium or higher exposure from earthquake. Of the total area in coastal shorline counties, 2.6 percent is ranked high, 2.37 percent is ranked medium-high, and 33.68 percent is ranked as medium for earthquake exposure. The higher degree of exposure in the coastal areas is indicative of the greater influence of the possible sources of earthquakes to the west of the state, most notably the Cascadia subduction zone, and higher susceptibily to liquefaction in these coastal areas.

All of Clallam, Grays Harbor, Island, Jefferson, Kitsap, Mason, and Pacific counties (all coastal shoreline counties) are ranked at medium or higher on earthquake hazard exposure. Among the non-coastal shoreline counties, the top three counties with highest percentage of land area ranked medium or higher for earthquake hazard exposure include Lewis (43.56 percent, with only 3.04 percent ranked high), Cowlitz (17.57 percent, with 0 percent ranked high), and Clark (14.96 percent, with 0 percent ranked high) counties. In all other non-coastal shoreline counties, less than 10 percent of the county area is ranked medium or higher for earthquake exposure.

Percentage of County Land Area in Different Categories of Earthquake Exposure

County	Low	Medium Low	Medium	Medium High	High
Adams	29.99	66.50	3.51	0.00	0.00
Asotin	96.39	2.15	1.46	0.00	0.00
Benton	16.46	79.50	4.04	0.00	0.00
Chelan	78.72	16.46	4.48	0.34	0.00
Clallam	0.00	0.00	94.76	1.28	3.96
Clark	0.00	85.04	8.47	6.50	0.00
Columbia	52.37	43.75	3.87	0.00	0.00
Cowlitz	0.00	82.43	10.43	7.14	0.00
Douglas	39.16	58.83	2.01	0.00	0.00
Ferry	81.46	18.02	0.51	0.00	0.00
Franklin	26.94	70.29	2.77	0.01	0.00
Garfield	77.43	20.65	1.92	0.00	0.00
Grant	35.27	62.07	2.66	0.00	0.00
Grays Harbor	0.00	0.00	89.83	0.38	9.79
Island	0.00	0.00	90.38	6.89	2.73
Jefferson	0.00	0.00	94.83	0.82	4.35
King	0.00	43.62	45.05	6.39	4.94
Kitsap	0.00	0.00	95.83	0.91	3.25
Kittitas	57.64	33.76	7.25	1.35	0.00
Klickitat	81.00	14.79	4.20	0.01	0.00
Lewis	0.00	56.44	36.13	4.39	3.04
Lincoln	60.38	36.99	2.63	0.00	0.00
Mason	0.00	0.00	95.47	0.73	3.80
Okanogan	70.86	26.68	2.46	0.00	0.00
Pacific	0.00	0.00	88.05	0.59	11.36
Pend Oreille	86.80	9.51	3.69	0.00	0.00
Pierce	0.00	38.06	54.29	3.72	3.93
San Juan	0.00	31.22	65.03	3.49	0.27
Skagit	15.98	52.93	18.11	10.48	2.51
Skamania	33.88	59.66	4.75	1.71	0.00
Snohomish	2.73	53.65	34.01	6.84	2.77
Spokane	83.32	12.74	3.94	0.00	0.00
Stevens	96.35	2.63	1.02	0.00	0.00
Thurston	0.00	1.48	81.81	9.81	6.91
Wahkiakum	0.00	37.47	47.71	6.63	8.18
Walla Walla	12.18	78.53	9.29	0.00	0.00
Whatcom	29.36	51.33	15.26	4.03	0.02
Whitman	83.85	7.77	8.38	0.00	0.00
Yakima	53.69	36.37	9.18	0.76	0.00
Washington State	**40.47**	**34.05**	**22.36**	**1.69**	**1.42**

Population Exposure

Population exposure to earthquake hazard was estimated by overlaying the earthquake hazard map layer on the 2011 developed areas derived from the land cover database. The 2017 estimated population for all census tracts was allocated to respective urban areas and the overlap with each category of earthquake exposure was estimated using spatial analysis in geographic Information System (GIS). Overall, 76.37 percent of the state population is estimated to reside in areas with medium or higher exposure from earthquakes. Majority of the state population (61.47 percent) resides in areas ranked at medium exposure from earthquakes. Only 8.26 percent of the population resides in areas with high exposure to earthquakes, and another 6.65 percent resides in areas with medium-high exposure to earthquakes. The high degree of population exposure to earthquake hazard is primarily a result of the increased concentration of state population concentrated in coastal shoreline counties, that have a higher percentage of area ranked medium or higher for earthquake exposure. King County has the maximum number of residents in areas ranked high for earthquake exposure, followed by Pierce and Snohomish counties.

Population Exposure to Earthquakes						
County	**Estimated Population Exposure to Earthquakes**					**Total Population**
	Low	Medium Low	Medium	Medium High	High	
Adams	4184	13241	2445	0	0	19870
Asotin	21871	0	413	0	0	22290
Benton	9652	162050	21798	0	0	193500
Chelan	9047	55747	12032	5	0	76830
Clallam	0	0	58349	2131	13481	74240
Clark	0	269187	173451	28362	0	471000
Columbia	0	0	4100	0	0	4100
Cowlitz	0	30625	24377	50898	0	105900
Douglas	4604	31624	5192	0	0	41420
Ferry	2947	1574	3049	0	0	7740
Franklin	8255	71222	10854	0	0	90330
Garfield	2200	0	0	0	0	2200
Grant	10803	79718	5110	0	0	95630
Grays Harbor	0	0	53591	9	19370	72970
Island	0	0	72077	6992	3721	82790
Jefferson	0	0	24646	0	6714	31360
King	0	1117	1686517	139178	326888	2153700
Kitsap	0	0	249704	5351	9244	264300
Kittitas	4104	17018	23608	0	0	44730
Klickitat	11771	7096	2792	0	0	21660
Lewis	0	5479	46086	11559	14316	77440
Lincoln	7973	2727	0	0	0	10700
Mason	0	0	58091	334	4765	63190

Population Exposure to Earthquakes

	Estimated Population Exposure to Earthquakes					Population
	Low	Medium Low	Medium	Medium High	High	
Okanogan	6487	19945	15608	0	0	42110
Pacific	0	0	15055	0	6195	21250
Pend Oreille	2195	10491	683	0	0	13370
Pierce	0	0	730748	13042	115610	859400
San Juan	0	480	14696	1322	12	16510
Skagit	0	7469	45320	45489	25556	124100
Skamania	3050	5647	2770	222	0	11690
Snohomish	0	12950	682124	55242	39083	789400
Spokane	383891	114383	1527	0	0	499800
Stevens	44202	0	308	0	0	44510
Thurston	0	0	169809	89757	17335	276900
Wahkiakum	0	1038	1515	1345	132	4030
Walla Walla	3886	18649	38865	0	0	61400
Whatcom	400	30292	149917	34624	1065	216300
Whitman	43873	264	4504	0	0	48640
Yakima	45798	125074	82128	0	0	253000
Washington State	631194	1095108	4493860	485866	603493	7310300

Vulnerable Population Exposure

The social vulnerability index was created for each of the census tracts using American Community Survey (ACS) 5-year data 2012-2016 (refer to technical appendix for more details). Social vulnerability data was first overlaid with developed areas extracted from the 2011 land cover database. Tract level social vulnerability estimated were assigned to respective developed areas in each of the tracts. This data was then overlaid with an earthquake hazard layer to identify developed areas with medium or higher social vulnerability that overlap with medium or higher earthquake exposure. Overall, only 8 percent of the total population residing in urban areas with medium or higher earthquake exposure is also ranked medium or higher on social vulnerability. In Adams County, 58 percent of the urban population with medium or higher earthquake exposure is also ranked medium or higher on social vulnerability. In Yakima County, almost 50 percent of population with medium or higher earthquake exposure is also ranked medium or higher on social vulnerability. None of the developed areas in Asotin, Chelan, Columbia, Ferry, Garfield, Island, Jefferson, Kitsap, Kittitas, Klickitat, Lincoln, Pend Oreille, San Juan, Skamania, Spokane and Wahkiakum counties are ranked medium or higher on both social vulnerability and earthquake exposure. King County, with the highest population exposed to medium or higher earthquake hazard, has almost 9 percent of this population also ranked medium or higher on social vulnerability.

Vulnerable Population Exposure to Earthquakes		
County	Medium or Higher Earthquake Hazard Exposure	
	Vulnerable Population (2017 Estimates)	Vulnerable Population (%) (Medium or higher Vulnerability)
Adams	2445	1419 (58.05)
Asotin	413	0 (0.00)
Benton	21798	1395 (6.40)
Chelan	12037	0 (0.00)
Clallam	73961	1960 (2.65)
Clark	201813	6579 (3.26)
Columbia	4100	0 (0.00)
Cowlitz	75275	13580 (18.04)
Douglas	5192	2154 (41.48)
Ferry	3049	0 (0.00)
Franklin	10854	4666 (42.99)
Garfield	0	0 (0.00)
Grant	5110	1659 (32.47)
Grays Harbor	72970	7465 (10.23)
Island	82790	0 (0.00)
Jefferson	31360	0 (0.00)
King	2152583	194378 (9.03)
Kitsap	264300	0 (0.00)
Kittitas	23608	0 (0.00)
Klickitat	2792	0 (0.00)
Lewis	71961	1231 (1.71)
Lincoln	0	0 (0.00)
Mason	63190	4948 (7.83)
Okanogan	15608	4531 (29.03)
Pacific	21250	2894 (13.62)
Pend Oreille	683	0 (0.00)
Pierce	859400	35751 (4.16)
San Juan	16030	0 (0.00)
Skagit	116365	5458 (4.69)
Skamania	2993	0 (0.00)
Snohomish	776450	25545 (3.29)
Spokane	1527	0 (0.00)
Stevens	308	13 (4.25)
Thurston	276900	0 (0.67)
Wahkiakum	2992	0 (0.00)
Walla Walla	38865	5352 (13.77)
Whatcom	185605	1114 (0.60)
Whitman	4504	714 (15.86)
Yakima	82128	39914 (48.60)
Washington State	5583219	450566 (8.07)

Built Environment Exposure

The built environment exposure to earthquake hazard is calculated using the general building stock data (2014) provided by FEMA that contains the building values for all structures in the census tracts. General building stock values used in this analysis are the total structure value of all buildings (except agricultural) in each census tract in 2014 dollars. Building values for all occupancy types were summed for each census tract using only structure values (not content values) and assigned to the developed areas within each tract. These maps were then overlaid on the earthquake hazard layer to estimate the general building stock value within medium or higher earthquake exposure areas. Individual tract level estimates were aggregated to create the county level estimates.

Overall, almost 50% of the general building stock of the state is in areas with medium or higher exposure to earthquake hazard. In three coastal shoreline counties – Grays Harbor, Pacific, and Wahkiakum, all the building stock is in areas at medium or higher exposure from earthquakes. King County has highest value of general building stock value located in areas at medium or higher exposure from earthquakes. Lewis, Clallam, and Thurston counties have more than 90% of the county building stock in areas exposed to medium or higher earthquake hazard. Jefferson and Island counties also have more than 75% of their building stock located in areas exposed to medium or higher earthquake hazard. Fifteen non-coastal shoreline counties Adams, Asotin, Benton, Chelan, Columbia, Douglas, Ferry, Franklin, Garfield, Grant, Kittitas, Klickitat, Lincoln, Okanogan, Pend Oreille, Skamania, Spokane, Stevens, Walla Walla, Whitman, and Yakima do not have any significant amount of general building stock situated in areas at medium or higher exposure from earthquake hazard.

Built Environment Exposure to Earthquakes

County	Total Value of General Building Stock (2014)	**In areas Ranked Medium or Higher for Earthquake Exposure**	
		Values of General Building Stock (2014)	Percent of Total GBS
Adams	$253,615	$0	0.00
Asotin	$1,061,235	$0	0.00
Benton	$6,529,565	$0	0.00
Chelan	$1,573,417	$0	0.00
Clallam	$2,427,219	$2,361,779	97.30
Clark	$32,074,170	$4,661,859	14.53
Columbia	$533	$0	0.00
Cowlitz	$4,992,730	$2,829,766	56.68
Douglas	$1,211,949	$0	0.00
Ferry	$1,521	$0	0.00
Franklin	$1,867,499	$0	0.00
Garfield	$437	$0	0.00
Grant	$583,022	$0	0.00
Grays Harbor	$1,162,104	$1,162,104	100.00
Island	$2,895,464	$2,177,273	75.20
Jefferson	$1,137,144	$983,632	86.50

Built Environment Exposure to Earthquakes			
County	Total Value of General Building Stock (2014)	In areas Ranked Medium or Higher for Earthquake Exposure	
		Values of General Building Stock (2014)	Percent of Total GBS
King	$362,698,022	$208,365,186	57.45
Kitsap	$17,267,166	$10,149,852	58.78
Kittitas	$530,126	$0	0.00
Klickitat	$4,479	$0	0.00
Lewis	$1,402,914	$1,388,260	98.96
Lincoln	$87,198	$0	0.00
Mason	$608,531	$271,112	44.55
Okanogan	$59,252	$0	0.00
Pacific	$125,715	$125,715	100.00
Pend Oreille	$8,310	$0	0.00
Pierce	$62,547,883	$29,752,902	47.57
San Juan	$225,856	$55,532	24.59
Skagit	$5,389,339	$2,736,579	50.78
Skamania	$17,391	$0	0.00
Snohomish	$52,406,666	$18,355,929	35.03
Spokane	$31,281,088	$0	0.00
Stevens	$325,218	$0	0.00
Thurston	$9,798,392	$8,863,054	90.45
Wahkiakum	$1,649	$1,649	100.00
Walla Walla	$3,061,065	$0	0.00
Whatcom	$15,241,051	$5,978,408	39.23
Whitman	$1,385,430	$0	0.00
Yakima	$7,986,979	$0	0.00
Washington State	$630,231,344	$300,220,591	47.64

Critical Infrastructure Exposure

Many major critical infrastructure facilities are likely to be impacted by seismic events. Older facilities (usually more than 30-years old and URM structures) and those not built to the updated building codes are likely to be significantly impacted by earthquakes. In some cases, even the facilities constructed under new building codes that reflect increased attention to seismicity could still be vulnerable to earthquakes. This is primarily because the data and scientific analysis relating to structural failure and performance of building materials during ground shaking are continually being improved.

Location of 12 critical infrastructure facilities including airports (23), communication towers (16,097), dams (268), education facilities (5,331), electric substations (1,392), hospitals (147), power plants (146), public transit stations (60), railroad bridges (1,619), railway stations (317), urgent care facilities (113) and weather radar stations (2), were derived from the Homeland Security Foundation Level Database (HIFLD). This data was overlaid with the earthquake hazard exposure layer to identify facilities located in medium or higher earthquake hazard zones. Spatial analysis of this dataset reveals that 45.61 percent of the critical infrastructure facilities in the state are in areas with medium or higher earthquake exposure. In nine coastal shoreline counties – Clallam, Grays Harbor, Island, Jefferson, Kitsap, Mason, Pacific, Thurston and Wahkiakum, all the critical infrastructure facilities are in areas at medium or higher exposure to earthquake hazard. In Pierce, Lewis, and King counties, more than 75 percent of the critical infrastructure facilities are in areas with medium or higher earthquake hazard exposure. In Snohomish County, almost 75 percent of the critical infrastructure facilities are in areas at medium or higher earthquake hazard exposure. However, in Adams, Asotin, Benton, Chelan, Columbia, Douglas, Ferry, Franklin, Garfield, Grant, Kittitas, Klickitat, Lincoln, Okanogan, Pend Oreille, Skamania, Spokane, Stevens and Whitman counties, all the critical infrastructure facilities are located outside of the areas at medium or higher exposure from earthquakes.

Critical Infrastructure Exposure			
County	Number of Critical Infrastructure Facilities	In areas Ranked Medium or Higher for Earthquake Exposure	
		Number of Critical Infrastructure Facilities	Percent of Critical Infrastructure Facilities
Adams	206	0	0.00
Asotin	81	0	0.00
Benton	664	0	0.00
Chelan	507	0	0.00
Clallam	273	273	100.00
Clark	490	171	34.90
Columbia	88	0	0.00
Cowlitz	474	222	46.84
Douglas	290	0	0.00
Ferry	83	0	0.00
Franklin	270	0	0.00
Garfield	89	0	0.00
Grant	501	0	0.00
Grays Harbor	377	377	100.00
Island	104	104	100.00
Jefferson	197	197	100.00
King	2761	2432	88.08
Kitsap	451	451	100.00
Kittitas	303	0	0.00
Klickitat	322	0	0.00
Lewis	374	330	88.24
Lincoln	237	0	0.00
Mason	152	152	100.00
Okanogan	359	0	0.00
Pacific	152	152	100.00
Pend Oreille	69	0	0.00

Critical Infrastructure Exposure			
County	Number of Critical Infrastructure Facilities	In areas Ranked Medium or Higher for Earthquake Exposure	
		Number of Critical Infrastructure Facilities	Percent of Critical Infrastructure Facilities
Pierce	1130	1049	92.83
San Juan	98	27	27.55
Skagit	474	216	45.57
Skamania	145	0	0.00
Snohomish	787	577	73.32
Spokane	933	0	0.00
Stevens	211	0	0.00
Thurston	462	462	100.00
Wahkiakum	17	17	100.00
Walla Walla	273	11	4.03
Whatcom	613	70	11.42
Whitman	409	0	0.00
Yakima	601	20	3.33
Washington State	16027	7310	45.61

State Operations and Facilities Exposure

The list of state owned (9,415) and leased facilities (1,039) was obtained from 2017 Facilities Inventory System Report produced by Office of Financial Management (detailed list included in Appendix I-2). These facilities were geo-located based on the addresses provided in the facilities inventory report and then overlaid with earthquake hazard layer. The spatial analysis reveals that almost 65 percent of the state-owned facilities are situated in areas exposed to medium or higher earthquake hazard. In all counties of the state, except for Yakima County, more than 50 percent of the state-owned facilities are situated in areas at medium or higher levels of earthquake exposure. In Clallam, Jefferson and Columbia counties more than 70 percent of the state-owned facilities are situated in areas at medium or higher earthquake exposure.

Overall, 71 percent of the state leased facilities are also situated in areas at moderate to high exposure from earthquakes. In Clallam, Jefferson, Columbia, Pacific, Skagit, Pierce, Walla Walla, Mason, Lewis, King, Island, Kitsap, Thurston, Grays Harbor and Snohomish counties all the state leased facilities are in areas at medium or higher earthquake exposure. In Ferry, Skamania, Spokane, Franklin, Klickitat, Stevens, Asotin, Adams, Douglas and Grant counties, none of the state-leased facilities are in areas at medium or higher earthquake exposure.

State Owned and Leased Facilities Exposure

County	State Owned Facilities	State Leased Facilities	In areas Ranked Medium or Higher for Earthquake Exposure			
			State Owned Facilities	Percent of State Owned Facilities	State Leased Facilities	Percent of State Leased Facilities
Adams	64	1	35	55	0	0
Asotin	90	6	50	56	0	0
Benton	159	30	97	61	5	17
Chelan	192	22	109	57	7	32
Clallam	183	12	132	72	12	100
Clark	229	23	144	63	20	87
Columbia	75	1	53	71	1	100
Cowlitz	128	18	83	65	11	61
Douglas	42	10	22	52	0	0
Ferry	32	3	21	66	0	0
Franklin	160	9	98	61	0	0
Garfield	21	0	13	62	0	0
Grant	252	15	131	52	0	0
Grays Harbor	224	13	142	63	13	100
Island	269	6	175	65	6	100
Jefferson	394	5	279	71	5	100
King	1120	226	732	65	226	100
Kitsap	269	15	175	65	15	100
Kittitas	348	11	225	65	8	73
Klickitat	110	10	65	59	0	0
Lewis	163	13	107	66	13	100
Lincoln	58	0	33	57	0	0
Mason	244	7	161	66	7	100
Okanogan	179	10	102	57	5	50
Pacific	233	6	160	69	6	100
Pend Oreille	18	5	9	50	2	40
Pierce	865	54	589	68	54	100
San Juan	282	5	183	65	3	60
Skagit	286	15	196	69	15	100
Skamania	64	2	42	66	0	0
Snohomish	270	71	167	62	71	100
Spokane	571	121	357	63	0	0
Stevens	65	7	38	58	0	0
Thurston	431	166	280	65	166	100
Wahkiakum	22	0	13	59	0	0
Walla Walla	159	11	106	67	11	100
Whatcom	283	32	181	64	27	84
Whitman	566	9	349	62	5	56
Yakima	294	61	138	47	16	26
Washington State	9415	1031	5992	64	731	71

First Responder Facilities Exposure

Locations of fire stations, law enforcement building, and emergency medical stations in the state were identified from the Homeland Security Foundation Level Database (HIFLD). Using ESRI ArcMap geocoding services 1,268 fire stations, 594 law enforcement agencies, and 1,162 EMS stations (including those co-located with fire stations) were located on the State map. It is estimated that 65 percent of the fire stations, 20 percent of the law enforcement buildings, and 69 percent of the EMS facilities are in areas identified at medium or higher earthquake exposure. In Clallam, Columbia, Garfield, Grays Harbor, Island, Jefferson, Kitsap, Mason, Pacific, San Juan and Thurston counties, all fire stations and EMS facilities are in areas at medium or higher exposure to earthquakes. All law enforcement buildings in Asotin and Garfield counties are also located in areas at medium or higher exposure to earthquakes. The two law enforcement buildings in Asotin County are also located in areas at medium or higher exposure to earthquakes.

First Responder Facilities Exposure to Earthquakes									
County	Fire Station			Law Enforcement			EMS		
	Total Number of Facilities	In areas Ranked Medium or Higher for Earthquake Exposure		Total Number of Facilities	In areas Ranked Medium or Higher for Earthquake Exposure		Total Number of Facilities	In areas Ranked Medium or Higher for Earthquake Exposure	
		Number of facilities	Percent Facilities		Number of facilities	Percent Facilities		Number of facilities	Percent Facilities
Adams	11	1	9.09	5	0	0.00	5	1	20.00
Asotin	3	1	33.33	2	2	100.00	2	0	0.00
Benton	29	2	6.90	27	1	3.70	27	3	11.11
Chelan	30	5	16.67	21	0	0.00	21	3	14.29
Clallam	22	22	100.00	24	5	20.83	24	24	100.00
Clark	40	10	25.00	40	7	17.50	40	10	25.00
Columbia	3	3	100.00	2	1	50.00	2	2	100.00
Cowlitz	25	17	68.00	17	7	41.18	17	12	70.59
Douglas	12	2	16.67	8	0	0.00	8	2	25.00
Ferry	12	1	8.33	5	0	0.00	5	1	20.00
Franklin	20	1	5.00	15	2	13.33	15	0	0.00
Garfield	2	2	100.00	1	1	100.00	1	1	100.00
Grant	50	8	16.00	28	1	3.57	28	4	14.29
Grays Harbor	32	32	100.00	20	9	45.00	20	20	100.00
Island	10	10	100.00	9	4	44.44	9	9	100.00
Jefferson	12	12	100.00	13	4	30.77	13	13	100.00
King	159	157	98.74	161	59	36.65	161	159	98.76
Kitsap	47	47	100.00	49	6	12.24	49	49	100.00
Kittitas	33	16	48.48	33	2	6.06	33	14	42.42
Klickitat	36	6	16.67	25	0	0.00	25	3	12.00
Lewis	51	49	96.08	50	11	22.00	50	48	96.00
Lincoln	10		0.00	9	0	0.00	9	0	0.00
Mason	46	46	100.00	47	3	6.38	47	47	100.00

First Responder Facilities Exposure to Earthquakes

County	Fire Station			Law Enforcement			EMS		
	Total Number of Facilities	In areas Ranked Medium or Higher for Earthquake Exposure		Total Number of Facilities	In areas Ranked Medium or Higher for Earthquake Exposure		Total Number of Facilities	In areas Ranked Medium or Higher for Earthquake Exposure	
		Number of facilities	Percent Facilities		Number of facilities	Percent Facilities		Number of facilities	Percent Facilities
Okanogan	27	11	40.74	17	3	17.65	17	7	41.18
Pacific	16	16	100.00	10	5	50.00	10	10	100.00
Pend Oreille	18	3	16.67	16	0	0.00	16	3	18.75
Pierce	99	97	97.98	101	29	28.71	101	99	98.02
San Juan	4	4	100.00	5	1	20.00	5	5	100.00
Skagit	39	38	97.44	40	6	15.00	40	39	97.50
Skamania	3		0.00	3	1	33.33	3	0	0.00
Snohomish	74	73	98.65	73	23	31.51	73	72	98.63
Spokane	52	4	7.69	50	0	0.00	50	4	8.00
Stevens	34		0.00	27	0	0.00	27	0	0.00
Thurston	47	47	100.00	55	17	30.91	55	55	100.00
Wahkiakum	9	6	66.67	5	0	0.00	5	4	80.00
Walla Walla	21	13	61.90	20	3	15.00	20	12	60.00
Whatcom	50	40	80.00	54	9	16.67	54	44	81.48
Whitman	24	8	33.33	22	3	13.64	22	7	31.82
Yakima	56	21	37.50	53	6	11.32	53	22	41.51
Grand Total	1268	831	65.54	1162	231	19.88	1162	808	69.54

Washington State Risk Index for Earthquake (WaSRI-E)

The earthquake risk index (WaSRI-E) for each county is estimated as the average of the standardized rank of earthquake exposure (medium or higher exposure) assessments for county area, population, vulnerable populations, built environment, critical infrastructure facilities, state facilities and first responder facilities. The individual exposure assessment values were categorized into 5 classes (1: Low, 2: Medium-Low, 3: Medium, 4: Medium-High, and 5: High) using z-score transformation (standard deviations from the mean).

Classification Schema for Standardized Exposure Assessment Values	
Standard Deviation	Classification Rank
>1	High (5)
0.50 to 1.0	Medium-High (4)
0.5 to -0.5	Medium (3)
-0.5 to -1	Medium-Low (2)
< -1.0	Low (1)

The earthquake risk index (WaSRI-E) is the mean of these individual exposure rankings. While similar exposure assessment was also done for economic consequences and risk to environment (described in the next sections), these specific rankings were not included in the estimation of the earthquake risk index. Economic consequence rankings were not included because of data quality limitations. Economic consequences estimates are based on overall county data. Including them in the index is likely to result in biased estimation of earthquake risk. The natural environment only included a limited number of environmental resources. Each natural hazard is associate with specific effects on the natural environment and therefore adoption of a common scale across all hazard for environmental impacts is not appropriate.

The statistical analysis of earthquake exposure assessments reveals that five counties – Clallam, Grays Harbor, King, Pacific and Thurston are at the highest risk from earthquakes. These counties have high proportion of residents located in areas at medium or higher earthquake exposure. However, not all counties with high population exposure to earthquakes (medium or greater) are ranked high on the earthquake risk index. Six counties – Island, Jefferson, Kitsap, Mason, Pierce and Snohomish, ranked high on population exposure to earthquakes are ranked medium-high on earthquake risk because they have lower levels of earthquake exposure in other categories. Clallam County, ranked high on the earthquake risk index, also ranks high on population, built environment, critical infrastructure, and state facilities exposure to earthquake hazard. Grays Harbor County ranked high on earthquake risk index, also ranks high on population, built environment, critical infrastructure and first responder facilities exposure to earthquake hazard. King County ranked high on earthquake risk index, also ranks high on population, critical infrastructure, first responder facilities, and state facilities exposure to earthquake hazard. Chelan, Asotin, Benton, Klickitat, Lincoln, Pend Oreille, Spokane, and Stevens counties ranked low on the earthquake risk index are also ranked low across most of the earthquake exposure categories. Among these, Asotin County ranked medium on earthquake exposure to first responder facilities; Chelan, Benton, Klickitat, and Lincoln counties are ranked medium-low for state facilities exposure to earthquakes.

Earthquake Risk Index (WaSRI E) and Constituent Earthquake Exposure Ranks for Each County

County	Area	Population	Vulnerable Population	Built Environment	Critical Infrastructure	State Facilities	First Responder Facilities	**Earthquake Risk Index (WaSRI E)**
Adams	Low	Low	High	Low	Low	Medium-Low	Low	**Medium-Low**
Asotin	Low	Low	Low	Low	Low	Low	Medium	**Low**
Benton	Low	Low	Medium-Low	Low	Low	Medium-Low	Low	**Low**
Chelan	Low	Medium-Low	Low	Low	Low	Medium-Low	Low	**Low**
Clallam	High	High	Medium-Low	High	High	High	Medium-High	**High**
Clark	Medium -Low	Medium	Medium-Low	Medium-Low	Medium	Medium	Medium-Low	**Medium**
Columbia	Low	High	Low	Low	Low	High	High	**Medium**
Cowlitz	Medium	Medium	Medium	Medium	Medium	Medium	Medium	**Medium**
Douglas	Low	Low	High	Low	Low	Low	Medium-Low	**Medium-Low**
Ferry	Low	Medium	Low	Low	Low	Medium	Low	**Medium-Low**
Franklin	Low	Low	High	Low	Low	Medium	Low	**Medium-Low**
Garfield	Low	Low	Low	Low	Low	Medium	High	**Medium-Low**
Grant	Low	Low	Medium-High	Low	Low	Low	Low	**Medium-Low**
Grays Harbor	High	High	Medium	High	High	Medium	High	**High**
Island	High	High	Low	Medium	High	Medium-High	High	**Medium-High**
Jefferson	High	High	Low	Medium-High	High	High	Medium-High	**Medium-High**
King	Medium	High	Medium	Medium	High	High	High	**High**
Kitsap	High	High	Low	Medium	High	Medium-High	Medium-High	**Medium-High**
Kittitas	Medium -Low	Medium	Low	Low	Low	Medium	Medium	**Medium-Low**
Klickitat	Low	Low	Low	Low	Low	Medium-Low	Low	**Low**
Lewis	Medium	Medium-High	Medium-Low	High	High	Medium-High	Medium-High	**Medium-High**
Lincoln	Low	Low	Low	Low	Low	Medium-Low	Low	**Low**
Mason	High	High	Medium	Medium-Low	High	Medium-High	Medium-High	**Medium-High**
Okanogan	Low	Medium	Medium-High	Low	Low	Medium-Low	Medium	**Medium**
Pacific	High	High	Medium	High	High	Medium-High	High	**High**
Pend Oreille	Low	Low	Low	Low	Low	Low	Low	**Low**

Earthquake Risk Index (WaSRI E) and Constituent Earthquake Exposure Ranks for Each County								
County	Area	Population	Vulnerable Population	Built Environment	Critical Infrastructure	State Facilities	First Responder Facilities	**Earthquake Risk Index (WaSRI E)**
Pierce	Medium -High	High	Medium-Low	Medium-Low	High	High	Medium-High	**Medium-High**
San Juan	Medium -High	High	Low	Medium-Low	Medium	Medium	Medium-High	**Medium**
Skagit	Medium	Medium-High	Medium-Low	Medium-Low	Medium	High	Medium-High	**Medium-High**
Skamania	Medium -Low	Medium-Low	Low	Low	Low	Medium	Low	**Medium-Low**
Snohomish	Medium	High	Medium-Low	Medium-Low	Medium-High	Medium-High	Medium-High	**Medium-High**
Spokane	Low	Low	Low	Low	Low	Low	Low	**Low**
Stevens	Low	Low	Medium-Low	Low	Low	Low	Low	**Low**
Thurston	High	High	Medium-Low	Medium-High	High	High	Medium-High	**High**
Wahkiakum	Medium -High	Medium	Low	High	High	Medium	Medium	**Medium-High**
Walla Walla	Medium -Low	Medium	Medium	Low	Medium-Low	Medium-High	Medium	**Medium**
Whatcom	Medium	Medium-High	Medium-Low	Medium-Low	Medium-Low	Medium-High	Medium	**Medium**
Whitman	Medium -Low	Low	Medium	Low	Low	Medium	Medium-Low	**Medium-Low**
Yakima	Medium -Low	Medium-Low	High	Low	Medium-Low	Low	Medium	**Medium**

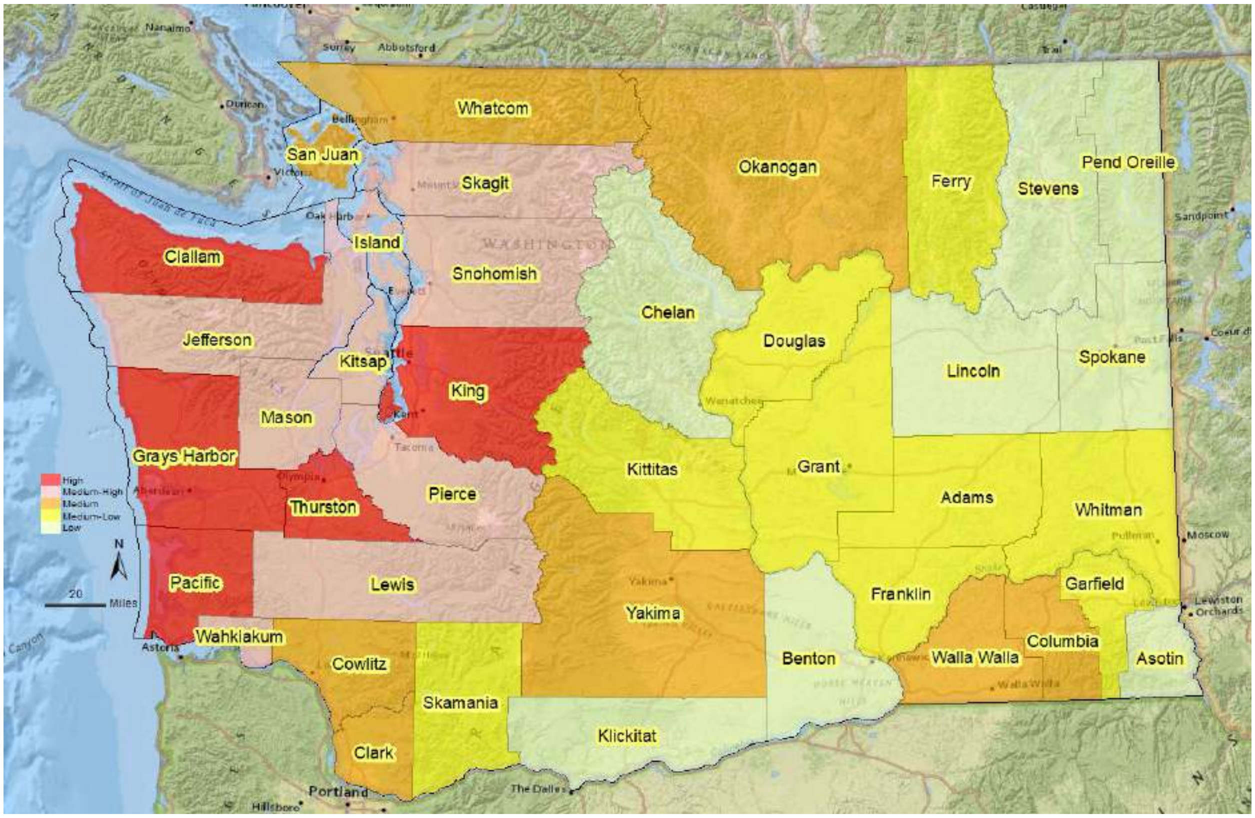


FIGURE E 11: WASHINGTON EARTHQUAKE RISK INDEX (WASRI-E)

Economic Consequences

The economic activity data was derived from National Association of Counties. This dataset provides the county level estimates of Gross Domestic Product (GDP) for 2016. The five counties ranked high on the earthquake risk index contribute 54percent of the State Gross Domestic Product. Among these, King county contributes 50percent of the State GDP. The other four counties – Thurston Clallam, Grays Harbor, and Pacific cumulatively contribute only 4percent to the State GDP. The next three significant contributors (more than 5percent) to State GDP – Pierce, Snohomish, and Spokane counties, are ranked medium-high, medium-high, and low, respectively on the earthquake risk index. Overall, 22 counties ranked medium or higher on the earthquake risk index cumulatively are responsible for 87.75percent of the state GDP. Thus, a major earthquake that impacts these counties will likely cripple the State economy.

Earthquake Risk (WaSRI E) and County GDP 2016		
County	Earthquake Risk Index (WaSRI E)	GDP 2016 (in Mil.)
Adams	Medium-Low	$746.07
Asotin	Low	$618.43
Benton	Low	$10,627.85
Chelan	Low	$4,363.01
Clallam	High	$2,573.06
Clark	Medium	$18,682.64

Earthquake Risk (WaSRI E) and County GDP 2016		
County	Earthquake Risk Index (WaSRI E)	GDP 2016 (in Mil.)
Columbia	Medium	$144.20
Cowlitz	Medium	$4,474.88
Douglas	Medium-Low	$1,037.39
Ferry	Medium-Low	$198.13
Franklin	Medium-Low	$3,356.16
Garfield	Medium-Low	$97.44
Grant	Medium-Low	$3,803.65
Grays Harbor	High	$2,237.44
Island	Medium-High	$2,796.80
Jefferson	Medium-High	$867.23
King	High	$230,344.61
Kitsap	Medium-High	$12,082.18
Kittitas	Medium-Low	$1,566.21
Klickitat	Low	$1,004.05
Lewis	Medium-High	$2,573.06
Lincoln	Low	$347.25
Mason	Medium-High	$1,566.21
Okanogan	Medium	$1,678.08
Pacific	High	$637.45
Pend Oreille	Low	$354.63
Pierce	Medium-High	$41,280.80
San Juan	Medium	$602.88
Skagit	Medium-High	$5,705.48
Skamania	Medium-Low	$218.04
Snohomish	Medium-High	$39,378.97
Spokane	Low	$24,723.73
Stevens	Low	$1,111.56
Thurston	High	$12,865.29
Wahkiakum	Medium-High	$93.41
Walla Walla	Medium	$2,908.67
Whatcom	Medium	$10,068.49
Whitman	Medium-Low	$2,237.44
Yakima	Medium	$10,404.10

Risk to Environment

To assess the risk to environmental resources, the spatial land cover mapped data was overlaid with earthquake hazard layer. Forests, scrubland, wetland, and cropland areas were identified as ecologically critical areas. The overlap between these areas of ecological importance and earthquake hazard was analyzed through spatial analysis in GIS software. It is estimated that 23percent of the State's ecologically critical resources are in areas at medium or higher risk from earthquake hazard. All ecologically critical areas in Clallam, Grays Harbor, Island, Jefferson, Kitsap, Mason, and Pacific counties are in regions of medium or higher earthquake exposure. In Thurston, San Juan, Wahkiakum, and Pierce counties more that 50percent of the ecologically critical areas are in medium or higher earthquake exposure regions.

Environmentally Critical Areas at Risk from Earthquakes	
County	Percent of County Ecologically Critical Area with Medium or Higher Earthquake Exposure
Adams	3.49
Asotin	1.42
Benton	3.62
Chelan	4.87
Clallam	100.00
Clark	9.13
Columbia	3.84
Cowlitz	15.89
Douglas	1.86
Ferry	0.52
Franklin	2.52
Garfield	1.94
Grant	2.69
Grays Harbor	100.00
Island	100.00
Jefferson	100.00
King	44.63
Kitsap	100.00
Kittitas	8.61
Klickitat	4.23
Lewis	42.90
Lincoln	2.65
Mason	100.00
Okanogan	2.40
Pacific	100.00
Pend Oreille	3.68
Pierce	53.39
San Juan	70.57
Skagit	29.62
Skamania	6.35
Snohomish	37.96
Spokane	4.11
Stevens	1.04
Thurston	98.30
Wahkiakum	61.71
Walla Walla	8.46
Whatcom	21.77
Whitman	8.44
Yakima	9.57
Washington State	22.98

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APPENDIX E 1

Earthquake Scenarios Developed by Washington State Department of Natural Resources(2011)

The following is the list of deterministic earthquake scenarios summarized in this section. The following analysis was done by Washington State Department of Natural Resources. Detailed information for each of these scenarios is available in Washington state seismic hazards catalog accessible at https://fortress.wa.gov/dnr/seismicscenarios/.

List of Washington Earthquake Scenarios

Earthquake scenario	M_w	Earthquake type
Boulder Creek	6.8	Crustal
Canyon River Price Lake	7.4	Crustal
Cascadia	9.0	Subduction zone
Cascadia (North)	8.3	Subduction zone
Chelan	7.2	Crustal
Cle Elum	6.8	Crustal
Devils Mountain	7.1	Crustal
Devils Mountain (West)	7.4	Crustal
Hite	6.8	Crustal
Lake Creek	6.8	Crustal
Mill Creek	7.1	Crustal
Mt. St. Helens	7.0	Crustal

List of Washington Earthquake Scenarios		
Earthquake scenario	M_w	Earthquake type
Olympia	6.8	Crustal
Saddle Mountain	7.35	Crustal
SeaTac	7.2	Intraplate
Seattle	7.2	Crustal
Spokane	5.5	Crustal
Southern Whidbey Island Fault	7.4	Crustal
Tacoma	7.1	Crustal

Boulder Creek Fault Zone in Whatcom County - M 6.8 Earthquake

Geological Description

The Boulder Creek fault zone in Northern Whatcom County consists of at least two fault strands. The M6.8 earthquake scenario for the zone is based on a 10.8 (6.7 mile)-kilometer-long rupture of one of these fault strands near the town of Kendall. Known as the Boulder Creek fault, this strand appears on early geologic maps of the area as a normal fault separating Eocene sedimentary rocks from Mesozoic metamorphic and igneous rocks. A second strand of the fault zone (unnamed) is located along the north side of the Nooksack River near Glacier, Washington. Both faults show geological evidence of earthquakes in the recent past.

Lidar (light detection and ranging) images of Whatcom County revealed two fault scarps along the North Fork Nooksack River. One scarp lies on the mapped trace of the Boulder Creek fault between Kendall and Maple Falls (Kendall scarp). The other (Canyon Creek) lies near an inferred fault. The Kendall scarp is about 4.3 kilometers (2.7 miles) long, south-side-up, and has a maximum preserved height of about 3 meters (9.8 feet). The Canyon Creek scarp is about 2 kilometers (1.2 miles) long, south-side-up and has a maximum height of about 4 meters (13 feet).

Four trenches dug across the Kendall scarp and one dug across the Canyon Creek scarp exposed faulted and folded glacial outwash deposits and Holocene soils. The trenches reveal a history of large earth quakes on the fault through the Holocene. The youngest earthquake occurred about 1,000 years ago and had 40 to 70 centimeters (15.8–28 inches) of reverse vertical separation. The next oldest occurred about 2,800 to 3,200 years ago. It had between ~25 centimeters (9.8 inches) and 1.7 meters (5.6 feet) of reverse vertical separation. These two earthquakes account for between ~80 percent and 95 percent of the total scarp height, suggesting that the earlier folding event created only a small scarp or that little of the original scarp was preserved on the landscape prior to the earthquake about 3,000 years ago.

Type of Earthquake

Most earthquake hazards result from ground shaking caused by seismic waves that radiate out when it ruptures. Seismic waves transmit the energy released by the earthquake. The bigger the earthquake, the larger the waves and the longer they last. Several factors affect the strength, duration, and pattern of shaking:

1. The type of rock and sediment layers that the waves travel through.
2. The dimensions and orientation of the fault and the characteristics of rapid slippage along it during an earthquake.
3. How close the rupture is to the surface of the ground.

Deep vs. Shallow: The M6.8 scenario earthquake modeled for the Boulder Creek fault is a shallow or crustal earthquake. Shallow quakes tend to be much more damaging than deep earthquakes of comparable magnitude (such as the deep M6.8 Nisqually earthquake in 2001). This is primarily because in deeper earthquakes, the seismic waves lose a majority of its energy by the time they reach the surface.

Aftershocks: Unlike deep earthquakes, which usually produce few or no aftershocks strong enough to be felt, a M6.8 shallow earthquake like the one in this scenario would likely be followed by many aftershocks, a few of which could be large enough to cause additional damage.

Other Damaging Effects

Liquefaction: If sediments (loose soils consisting of silt, sand, or gravel) are water-saturated, strong shaking can disrupt the grain-to-grain contacts, causing the ground to lose its strength. Increased pressure on the water between the grains sometimes produces small geyser-like eruptions of water and sediment called sand blows. Sediment in this condition is liquefied and behaves as a fluid. Buildings on such soils can sink and topple. Additionally, building foundations can lose strength, resulting in severe damage or structural collapse. Pipes, tanks, and other structures that are buried in liquefied soils will float upward to the surface.

Artificial fills, tidal flats, and stream sediments are often poorly consolidated and tend to have high liquefaction potential. For example, in the Boulder Creek scenario, the liquefaction susceptibility of the land on either side of the Skagit and Nooksack rivers is rated moderate to high.

Landslides: Earthquake shaking may cause landslides on slopes, particularly where the ground is water-saturated or has been modified (for example, by the removal of stabilizing vegetation). Steeper slopes are most susceptible, but old, deep-seated landslides may be reactivated, even where gradients are as low as 15 percent. Catastrophic debris flows can move water-saturated materials rapidly and for long distances, mostly in mountainous regions. Underwater slides are also possible, such as around river deltas.

HAZUS Results for the Boulder Creek Scenario

HAZUS is a nationally applicable standardized methodology developed by FEMA to help planners estimate potential losses from earthquakes. Local, state, and regional officials can use such estimates to plan risk-reduction efforts and prepare for emergency response and recovery.

HAZUS was used to estimate the earthquake-induced losses that could result from a M6.8 scenario earthquake on the Boulder Creek fault in Whatcom County. Such an event is expected to impact eight counties in Washington with the most significant effects apparent in Whatcom and Skagit counties.

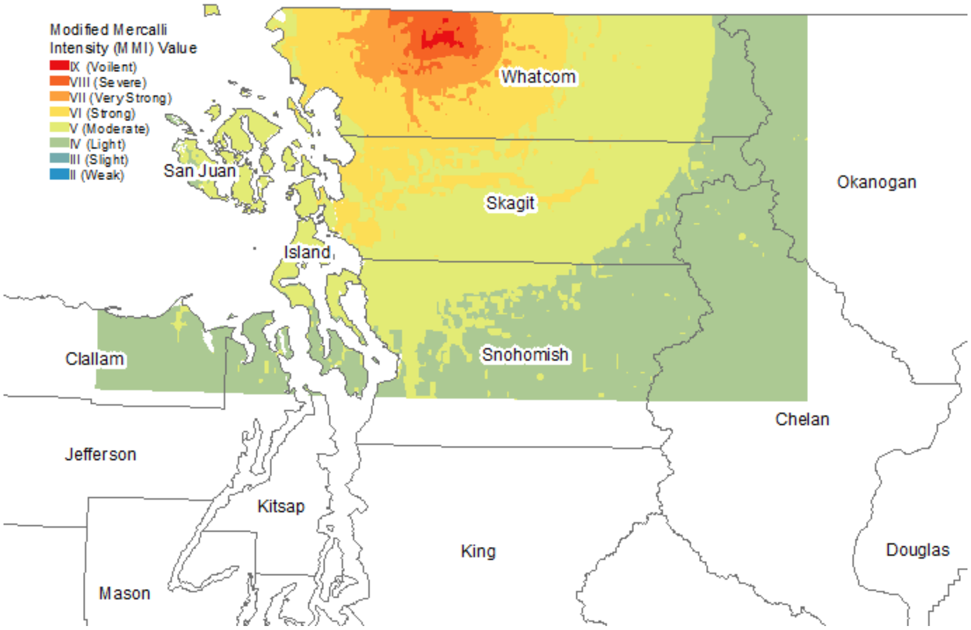


FIGURE AE 1: BOULDER CREEK M6.8 SHAKING INTENSITY

Summary of Significant Losses Boulder Creek Fault Scenario Earthquake	
End-to-end length of fault (kilometers)	11
Magnitude (M) of scenario earthquake	6.8
Number of counties impacted	8
Total injuries (*severity 1, 2, 3, 4) at 2:00 PM	15
Total number of buildings extensively damaged	77
Income losses in millions	$13
Capital stock losses in millions	$106
Debris total in millions of tons	0.02

Summary of Significant Losses Boulder Creek Fault Scenario Earthquake	
Truckloads of debris (25 tons per truckload)	760

Injuries: The estimated number of people injured in this scenario is relatively low. Most of injuries requiring medical attention or hospitalization occur in Skagit and Whatcom counties.

Damage: Buildings in most counties are likely to incur only slight damage, with moderate damage in a few cases. Skagit, Whatcom, and Snohomish counties may have the greatest number of buildings affected by this earthquake. Of these, most will be residential. Although damage will be slight to moderate for most of structures, 77 buildings will be extensively damaged. These structures are in Skagit and Whatcom counties and include residential, agricultural, commercial, and industrial buildings.

Economic Losses Due to Damage: Capital stock losses are the direct economic losses associated with damage to buildings, including the cost of structural and non-structural damage, damage to contents, and loss of inventory. Whatcom County accounts for the largest portion of the capital stock loss estimate (about $85 million), followed by Skagit (just under $16 million) and Snohomish (about $3 million).

Income losses, including wage losses and loss of rental income due to damaged buildings, are also highest in Whatcom County (approximately $10.5 million) and Skagit County (nearly $2 million).

Impact on Households and Schools: The majority of displaced households will occur in Whatcom and Skagit counties, with the largest number in Whatcom. The estimated number of individuals who will require shelter after the earthquake is moderately low. In this case, Whatcom County alone accounts for the total. The earthquake may impact the functionality of some schools on Day 1, particularly in Whatcom County; but for most counties, this impact is not expected to be significant.

Debris Removal: Following an earthquake, debris consisting of brick, wood, concrete, and steel will have to be removed and disposed of. The estimated total for this scenario is 19,000 tons (or 760 truckloads) of debris. All of this comes from Whatcom (16,000 tons) and Skagit (3,000 tons) counties.

Estimates vs. Actual Damage: Although the M6.8 earthquake scenario for the Boulder Creek fault zone was modeled using the best scientific information available, it represents a simplified version of expected ground motions. The damage resulting from an actual earthquake of similar magnitude is likely to be even more variable and will depend on the specific characteristics and environment of each affected structure.

Canyon River-Saddle Mountain Fault Zone Magnitude 7.4

Geological Description

The M7.4 earthquake scenario modeled for the Canyon River–Saddle Mountain fault zone (CRSM) is based on a 30 kilometer (19 mile)-long rupture of the fault zone between Lake Wynoochee and Lilliwaup. The CRSM fault zone is located along the southeastern flank of the Olympic Mountains. It roughly parallels the contact between the upper and lower members of the Paleocene Crescent Formation (basalt) near Lake Cushman. The fault zone is expressed topographically as three parallel scarps that are traced from Lilliwaup swamp, through the outfall of Price Lake, across the southern end of Lake Cushman, and on to the Canyon River near Lake Wynoochee. A detailed analysis of aeromagnetic data suggests the CRSM is a zone of deformation approximately 45 kilometers (28 miles) long that may accommodate northward shortening of crust beneath the Puget Lowland east of the Olympic Mountains.

Scarps revealed by LIDAR (light detection and ranging) surveys and recent paleoseismic studies demonstrate that the CRSM fault zone is active and has a recent history of large earthquakes. Trenching studies on the Canyon River fault focused on a 3 meter (10 foot)-high, north-facing scarp. Strata observed on the fault plane exposed by the trench show that past movement was oblique left-lateral-reverse faulting and was predominantly strike-slip. A single late Holocene event about 1,800 years ago had 3.7 to 7.9 meters of slip, suggesting a M6.7 to 7.8 earthquake. Trenching studies on the Saddle Mountain fault near Price Lake suggest multiple surface-rupturing earthquakes on the Saddle Mountain fault zone in the last 17,000 years. Recent trenching suggests two to four Holocene earthquakes (most likely two) on the Saddle Mountain fault zone.

Type of Earthquake

The M7.4 scenario earthquake modeled for the Canyon River–Saddle Mountain fault zone is a shallow or crustal earthquake. Shallow quakes tend to be much more damaging than deep quakes of comparable magnitude (such as the deep M6.8 Nisqually earthquake in 2001). This is primarily because in deeper earthquakes, the seismic waves lose a majority of its energy by the time they reach the surface.

Aftershocks: Unlike deep earthquakes, which usually produce few or no aftershocks strong enough to be felt, a M7.4 shallow earthquake like the one in this scenario would likely be followed by many aftershocks, a few of which could be large enough to cause additional damage.

HAZUS Results for the Canyon River-Saddle Mountain Earthquake Scenario

HAZUS was used to estimate the losses that could result from a M7.4 earthquake on the Canyon River– Price Lake fault zone in Mason County. Such an event is expected to impact eight counties, with the most significant effects apparent in Mason, King, Pierce, Kitsap and Thurston counties.

Summary of Losses in the M7.4 Canyon River Saddle Mountain Scenario Earthquake	
End-to-end length of fault (kilometers)	30
Magnitude (M) of scenario earthquake	7.4
Number of counties impacted	12
Total injuries (*severity 1, 2, 3, 4) at 2:00 PM	117
Total number of buildings extensively damaged	511
Total number of buildings completely damaged	26
Income losses in millions	$79
Capital stock losses in millions	$719
Debris total in millions of tons	0.12
Truckloads of debris (25 tons per truckload)	4,520
People without power (Day 1)	166
People without potable water (Day 1)	1,185

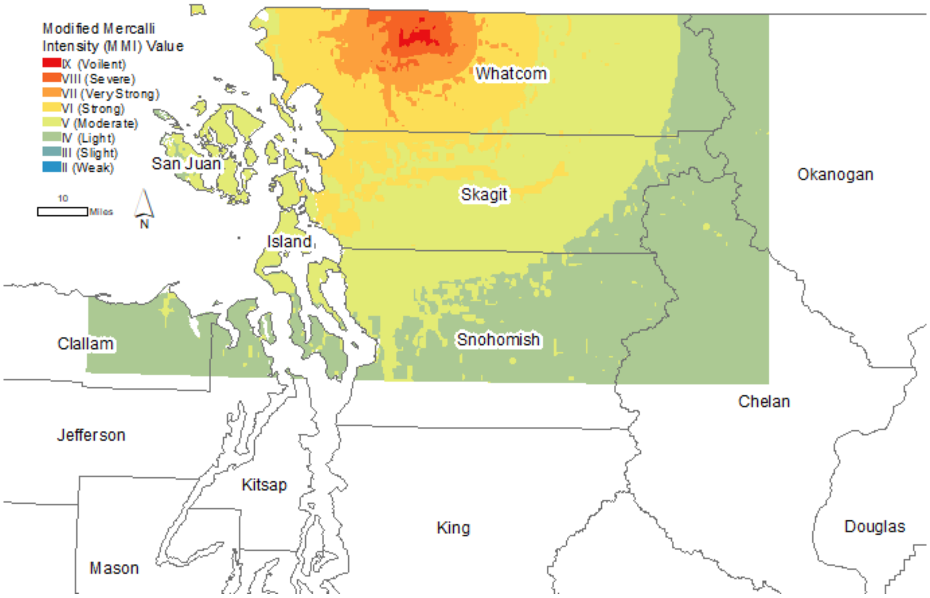


FIGURE AE 2: CANYON RIVER-SADDLE MOUNTAIN M7.4 SHAKING INTENSITY

Injuries: Most of those who are injured will need medical attention but not hospitalization. A few, more serious cases are estimated for Mason, King, Pierce, Kitsap and Thurston counties. The majority of these injuries will not be life-threatening; however, numerous fatalities are possible.

Damage: More than 37,000 buildings in Mason, King, Kitsap, Pierce, Thurston, Grays Harbor and Pacific counties are expected to incur damage; although in most cases, the damage will be slight to moderate. Several hundred buildings will be extensively or completely damaged, the majority in Mason County. Most of the damaged structures will be residential, commercial, and industrial.

Economic Losses Due to Damage: Capital stock losses are the direct economic losses associated with damage to buildings, including the cost of structural and non-structural damage, damage to contents, and loss of inventory. King County accounts for the largest portion of the capital stock loss estimate (about $271 million), followed by Pierce (about $119 million), Mason (just under $87 million), and Kitsap (about $85 million).

Income losses, including wage losses and loss of rental income due to damaged buildings, are highest in King County (about $27 million) and Mason County (nearly $15 million).

Impact on Households and Schools: The majority of people projected to be without power on Day 1 are located within Mason County. Those without potable water are in Mason and Kitsap counties. The highest number of displaced households will be in Kitsap County, followed by King and Mason counties. The estimated number of individuals who will require shelter after the earthquake is also highest in Kitsap County. The earthquake may impact the functionality of some schools on Day 1, particularly in Mason County; but for most counties, this impact is not expected to be significant.

Debris Removal: Following an earthquake, debris consisting of brick, wood, concrete, and steel will have to be removed and disposed of. Most of the estimated number of truckloads will come from King, Mason, and Pierce counties.

Estimates vs. Actual Damage: Although this M7.4 earthquake scenario was modeled using the best scientific information available, it represents a simplified version of expected ground motions. The damage resulting from an actual earthquake of similar magnitude is likely to be even more variable and will depend on the specific characteristics and environment of each affected structure.

Cascadia Subduction Zone off the Pacific Coast Magnitude 9.0 Earthquake

Geologic Description

The coastline of the Northwestern U.S. and Canada is bordered by an active subduction zone where the Juan de Fuca plate is subducting, or being pushed, beneath the North American plate. Currently, the subduction zone is considered locked (that is, it is not slipping). Strain is therefore accumulating on the locked interface between the plates. Plate convergence is estimated to be between 3 and 4 centimeters per year and possibly as high as 5.8 centimeters per year (the long-term geologically estimated rate).

The M9.0 Cascadia scenario is based on an approximately 1,000 kilometer (620 mile)-long rupture of the Cascadia subduction zone megathrust fault. The rupture extends from Cape Mendocino, California, to central Vancouver Island, Canada. This scenario is based on geologic evidence that indicates such ruptures occurred on the megathrust in the past. The last rupture was on January 26, 1700. Geologic evidence suggests that the average recurrence of ~M9.0 earthquakes along the Cascadia megathrust is about 500 years, but recurrence intervals vary, ranging from about 250 years to over 1,000 years. The effects of these earthquakes include strong ground shaking that goes on for several minutes, subsidence and/or uplift of coastal areas, liquefaction, and tsunami. Aftershocks will be both strong and numerous (possibly M7 or higher).

Type of Earthquake

Subduction zone earthquakes occur where the Juan de Fuca oceanic plate is being forced under the North American plate. An earthquake is produced when pressure that has built up along this zone, causing the plates to slip suddenly and rapidly past each other. Shaking from the M9.0 earthquake modeled in this scenario will be felt over the entire region and may last for several minutes. This event is like the 2011 Tohoku earthquake and tsunami in Japan.

Aftershocks: Unlike deep earthquakes, such as the M6.8 Nisqually earthquake in 2001, which usually produce few or no aftershocks strong enough to be felt, a M9.0 subduction zone earthquake will be followed by thousands of aftershocks, a few of which could be large enough to cause additional damage and produce tsunamis.

Other Earthquake Effects

A M9.0 Cascadia subduction zone earthquake is expected to generate a massive tsunami that will reach the coast of Washington about 20 to 30 minutes after the earthquake; waves may continue to strike the coastline for the next 12 to 24 hours. (Tsunami waves will also travel across the Pacific Ocean.) Delta failures and landslides caused by the shaking may also create or amplify tsunami waves.

HAZUS Results for the Cascadia Subduction Zone Scenario

HAZUS was used to estimate the losses that could result from a M9.0 earthquake on the Cascadia subduction zone. Such an event is expected to impact 23 counties in Washington. Among the most affected by the earthquake are Clallam, Grays Harbor, Jefferson, King, Mason, Pacific and Pierce. (These estimates do not include losses due to tsunami impacts.)

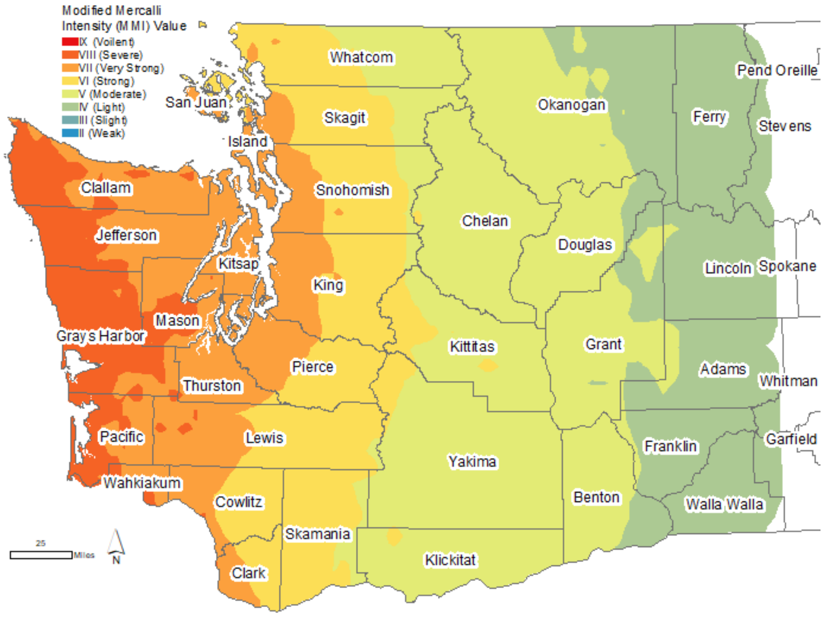


FIGURE AE 3: CASCADIA SUBDUCTION ZONE SCENARIO EARTHQUAKE M9.0 SHAKING INTENSITY

Summary of Significant Losses in M9.0 Cascadia Subduction Zone Scenario Earthquake	
End-to-end length of fault (kilometers)	1,100
Magnitude (M) of scenario earthquake	9.0
Number of counties impacted	23
Total injuries (*severity 1, 2, 3, 4) at 2:00 PM	7,534
Total number of buildings extensively damaged	43,681
Total number of buildings completely damaged	8,768
Income losses in millions	$3,811
Displaced households	18,385
People requiring shelter (individuals)	11,630
Capital stock losses in millions	$11,994
Debris total in millions of tons	5.68
Truckloads of debris (25 tons per truckload)	227,240

Injuries: The number of people injured in this scenario will be high. Estimates vary by location, ranging from several dozen (as in Jefferson County) to nearly 2,000 (in King County). Although many of the injuries will not be life-threatening, people in every county will require medical attention and, in many cases, hospitalization. Potentially life-threatening injuries and fatalities are expected; these are likely to be more numerous if the earthquake happens during the afternoon or early evening.

Damage: King County will have the greatest number of damaged buildings (more than 130,000). For other counties, the number is lower, but it often represents a much greater proportion of the county's building stock (as in Clallam, Grays Harbor, Pacific and Mason counties). Most of the damaged buildings will be residential, but the number of commercial and industrial structures expected to experience damage is also extremely high. The degree of damage will vary, but extensive damage to thousands of buildings is expected in Clallam, Grays Harbor, King, Mason, Pacific, and Pierce counties. Structural collapse (complete damage) of thousands of buildings is also expected (more than 3,000 in Clallam County).

Economic Losses Due to Damage: Capital stock losses are the direct economic losses associated with damage to buildings, including the cost of structural and non-structural damage, damage to contents, and loss of inventory. For this scenario, the estimates are substantial, ranging from more than $78 million in Jefferson County to over $3 billion in King County.

Income losses are high. This includes wage losses and loss of rental income due to damaged buildings King County alone accounts for over $1 billion.

Impact on Households and Schools: The number of people without power or water will be highest in King County (followed by Pierce, Grays Harbor, Pacific and Clallam). King, Grays Harbor and Pierce counties will have the highest number of displaced households and individuals in need of shelter. The functionality of many schools will be seriously affected by the earthquake. In Pacific County, functionality will initially be as low as 12 percent.

Debris Removal: Following this earthquake, debris (brick, wood, concrete, and steel) will have to be removed and disposed of. King County alone accounts for more than 1 million tons, Grays Harbor for 740,000 tons and Pierce for 583,000 tons.

Estimates vs. Actual Damage: Although this M9.0 earthquake was modeled using the best scientific information available, it represents a simplified version of expected ground motions. The damage resulting from an actual earthquake of similar magnitude is likely to be even more variable and will depend on the specific characteristics and environment of each affected structure.

Cascadia Subduction Zone along Washington's Outer Coast Magnitude 8.3 Earthquake

Geologic Description

The coastline of the northwestern U.S. and Canada is bordered by an active subduction zone where the Juan de Fuca plate is subducting, or being pushed, beneath the North American plate. The subduction zone is currently considered locked (that is, it is not slipping). Strain is therefore accumulating on the locked interface between the plates. Plate convergence is estimated at between 3 and 4 centimeters per year and possibly as much as 5.8 centimeters per year (the long-term geologically estimated rate).

The M8.3 Cascadia North scenario is based on an approximately 250 kilometer (155 miles)-long rupture of the Cascadia subduction zone megathrust fault. The entire megathrust extends from Cape Mendocino, California, to central Vancouver Island, Canada. This scenario is based on geologic evidence that indicates partial ruptures occur about one-third of the time on the megathrust and that these shorter ruptures are more prevalent south of the Columbia River. The last major earthquake on the megathrust ruptured the entire zone on January 26, 1700.

Geologic evidence suggests that the average recurrence of ~M9.0 earthquakes along the Cascadia megathrust is about 500 years, but recurrence intervals vary, ranging from about 250 years to more than 1,000 years.

The effects of these earthquakes include strong ground shaking that goes on for several minutes, subsidence and/or uplift of coastal areas, liquefaction, and tsunamis. Aftershocks will be both strong and numerous (possibly M7 or higher).

Type of Earthquake

In the Pacific Northwest, subduction zone earthquakes occur where the Juan de Fuca oceanic plate is being forced under the continental plate. An earthquake is produced when pressure that has built up along this zone, causing the plates to slip suddenly and rapidly past each other. Shaking from the M8.3 earthquake modeled in this scenario will be felt over a very large area and may last for several minutes.

Aftershocks: Unlike other deep earthquakes (such as the M6.8 Nisqually earthquake in 2001), which usually produce few or no aftershocks strong enough to be felt, a M8.3 subduction zone earthquake will be followed by many aftershocks, a few of which could be large enough to cause additional damage.

Other Earthquake Effects

Tsunamis: A M8.3 Cascadia subduction zone earthquake is expected to generate a tsunami.

Tsunami waves will reach the Pacific coast of Washington within 25 to 40 minutes of the earthquake and may continue for the next 12 to 24 hours. (Tsunami waves will also travel across the Pacific Ocean.) Delta failures and landslides caused by the shaking may also create or amplify tsunami waves.

HAZUS Results for the Cascadia Subductions Zone (North) Scenario

HAZUS was used to estimate the losses that could result from a M8.3 earthquake on the northern part of the Cascadia subduction zone. Such an event is expected to impact 23 counties in Washington. Among the most affected by the earthquake are Clark, Cowlitz, Grays Harbor, Lewis, Pacific, and Thurston. (Note: These estimates do not include losses due to tsunami.)

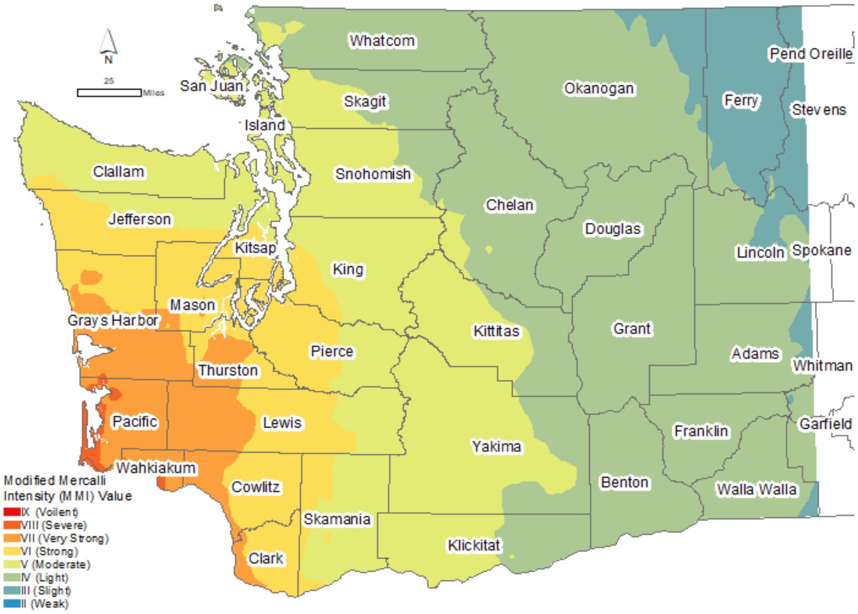


FIGURE AE 4: CASCADIA SUBDUCTION ZONE (NORTH) SCENARIO M8.5 SHAKING INTENSITY

Summary of Significant Losses M8.5 Cascadia Subduction Zone (North) Scenario	
End-to-end length of fault (kilometers)	275
Magnitude (M) of scenario earthquake	8.3
Number of counties impacted (WA only)	23
Total injuries (*severity 1, 2, 3, 4) at 2:00 PM	1,443
Total number of buildings extensively damaged	12,233
Total number of buildings completely damaged	1,940
Income losses in millions	$989
Displaced households	3,692
People requiring shelter (individuals)	2,452
Capital stock losses in millions	$2,708
Debris total in millions of tons	1.40
Truckloads of debris (25 tons per truckload)	55,920
People without potable water (Day 1)	2,858

Injuries: Many people will be injured in this earthquake. Estimates vary by location—from less than 100 in Thurston County to nearly 400 in Clark County. Although many of the injuries will not be life-threatening, they will require medical attention and, in dozens of cases, hospitalization. Potentially life-threatening injuries and fatalities are expected; these will be more numerous if the earthquake happens during the afternoon or early evening.

Damage: Clark and Thurston counties may have the greatest number of damaged buildings (over 48,000) in this scenario. The total damages for other counties are lower, but still amount to thousands of buildings (for example, over 17,000 in Grays Harbor). Most of the damaged buildings will be residential, but the totals include many commercial and industrial structures as well as other occupancy classes. The degree of damage will vary. In many counties, extensive damage to thousands of buildings is expected (with the highest numbers in Pacific, Grays Harbor, and Clark counties). Structural collapse of buildings is also expected (more than 1,200 in Pacific County alone). Many unreinforced masonry buildings will experience partial to full collapse.

Economic Losses Due to Damage: Capital stock losses are the direct economic losses associated with damage to buildings, including the cost of structural and non-structural damage, damage to contents, and loss of inventory. The estimates for this scenario are high, ranging from about $197 million in Lewis County to nearly $565 million in Clark County.

Income losses, including wage losses and loss of rental income due to damaged buildings, are also high: Clark County accounts for over $268 million.

Impact on Households and Schools: The number of households without water will be highest in Pacific County (over 2,500). Clark County is estimated to have the highest number of displaced households and individuals in need of shelter. The functionality of many schools will also be affected: On Day 1 in Pacific County, functionality may be as low as 32percent.

Debris Removal: Following this earthquake, debris (brick, wood, concrete, and steel) will have to be removed and disposed of. Clark County alone accounts for nearly 350,000 tons, Grays Harbor for 210,000 tons, and Cowlitz for 209,000 tons.

Estimates vs. Actual Damage: Although this M8.3 earthquake scenario was modeled using the best scientific information available, it represents a simplified version of expected ground motions. The damage resulting from an actual earthquake of similar magnitude is likely to be even more variable and will depend on the specific characteristics and environment of each affected structure.

Earthquake on the Chelan Fault Zone Magnitude 7.2

Geologic Description

The Chelan Earthquake scenario is based on a hypothetical fault rupture in the Chelan fault zone near Waterville in Douglas County. The scenario earthquake approximates a large earthquake that occurred in the Chelan region in 1872. The 1872 Earthquake is the largest upper plate earthquake to occur historically in the state of Washington. Early workers placed the earthquake anywhere from southern British Columbia to central Washington, but after an analysis of shaking reports following the 1872 Earthquake, seismologists concluded that it most likely occurred near Lake Chelan, Washington. They estimated the 1872 Earthquake at M6.5 to 7.0. In the seismic event modeled for the Chelan scenario, a north-northeast trending fault experiences a 56 kilometer (35 mile)-long rupture, resulting in a M7.2 earthquake. The modeled rupture area incorporates the epicentral region of the 1872 Earthquake and also covers the Chelan fault zone, an area of intense micro-seismicity near Entiat, Washington. No paleoseismology or slip rate information exists for this modeled fault.

Type of Earthquake

The magnitude 7.2 earthquake modeled for the Chelan scenario is a shallow or crustal earthquake. Shallow earthquakes tend to be much more damaging than deep earthquakes of comparable magnitude (such as the deep M6.8 Nisqually earthquake in 2001). This is primarily because in deeper earthquakes, the seismic waves lose a majority of its energy by the time they reach the surface.

<u>Aftershocks</u>: Unlike deep earthquakes, which usually produce few or no aftershocks strong enough to be felt, a M7.1 shallow earthquake like the one in this scenario would likely be followed by a significant number of aftershocks, a few of which could be large enough to cause additional damage.

HAZUS Results for the Chelan Fault Scenario

HAZUS was used to estimate the losses that could result from a M7.2 scenario earthquake on the Chelan fault in Douglas County. Such an event is expected to impact nine counties in Washington, with the most significant effects apparent in Chelan, Douglas, and Okanogan counties.

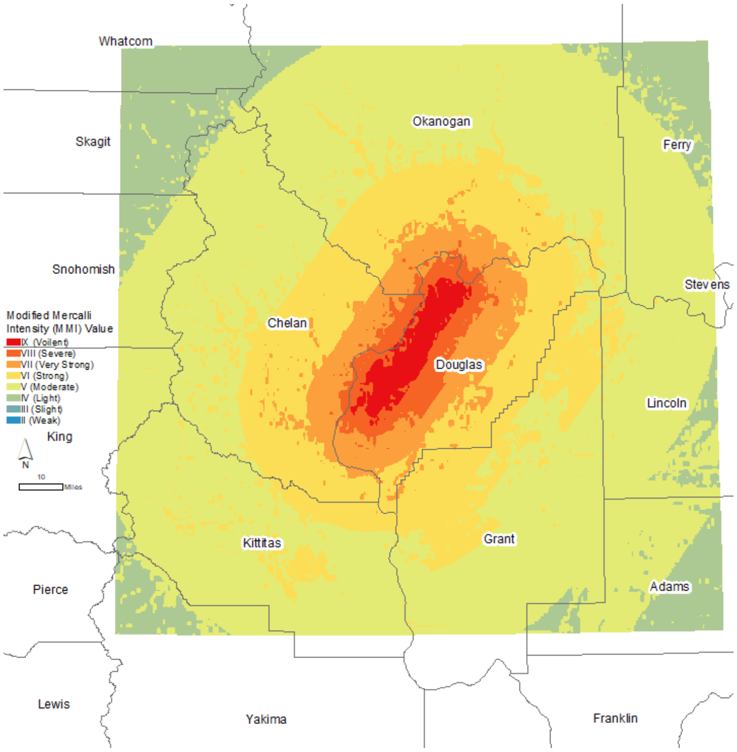


FIGURE AE 5: CHELAN FAULT ZONE MAGNITUDE 7.2 SCENARIO SHAKING INTENSITY

Summary of Significant Losses M7.2 Chelan Fault Scenario Earthquake	
End-to-end length of fault (kilometers)	56
Magnitude (M) of scenario earthquake	7.2
Number of counties impacted	9
Total injuries (*severity 1, 2, 3, 4) at 2:00 PM	31
Total number of buildings extensively damaged	375
Total number of buildings completely damaged	11
Income losses in millions	$30
Displaced households	33
Capital stock losses in millions	$151
Debris total in millions of tons	0.05
Truckloads of debris (25 tons per truckload)	1,680
People without power (Day 1)	0
People without potable water (Day 1)	466

Injuries: For most of the affected counties, the estimated number of people injured in this scenario is moderately low and most injuries will not be severe enough to require hospitalization. People in Chelan and Douglas counties, however, will experience both the greatest number of injuries and the most serious. Depending on what time of day the earthquake occurs, several fatalities are also likely.

Damage: The largest number of damaged buildings will be found in Douglas and Chelan counties. While much of this damage will be slight to moderate, hundreds of buildings will be extensively damaged (the majority in Douglas County). Some cases of extensive and complete damage are also expected in Grant and Okanogan counties. Although the majority of damaged buildings will be residential, commercial and industrial buildings are also expected to account for a large part of the total.

Economic Losses Due to Damage: Capital stock losses are the direct economic losses associated with damage to buildings, including the cost of structural and non-structural damage, damage to contents, and loss of inventory. Chelan County accounts for the largest portion of the capital stock loss estimate (more than $69.5 million), followed by Douglas County (about $55.4 million) and Grant County (nearly $13 million).

Income losses, including wage losses and loss of rental income due to damaged buildings, are also highest in Douglas County (more than $14 million) and Chelan County (about $11.5 million).

Impact on Households and Schools: Displaced households occur primarily in Douglas and Chelan counties, most in Douglas. The number of people who will require shelter is also highest for Douglas County. Schools in Douglas County will be only 54 percent functional on Day 1 after the earthquake; in Chelan County, schools may be 74 percent functional.

Debris Removal: Following an earthquake, debris consisting of brick, wood, concrete, and steel will have to be removed and disposed of. Douglas and Chelan counties will account for most of the debris (42,000 tons or 1,680 truckloads), followed by Grant, Okanogan, and Kittitas counties.

Estimates vs. Actual Damage: Although this M7.2 earthquake scenario was modeled using the best scientific information available, it represents a simplified version of expected ground motions. The damage resulting from an actual earthquake of similar magnitude is likely to be even more variable and will depend on the specific characteristics and environment of each affected structure.

Cle Elum Seismic Zone Magnitude 6.8 Earthquake

Geologic Description

The Cle Elum scenario is a M6.8 earthquake based on a hypothetical 30 kilometer (19 mile)-long rupture along a set of faults following the Manastash Ridge and the Cle Elum Ridge. The modeled rupture assumes slip on a fault running along the northern flank of Manastash Ridge, just south of Ellensburg, and continuing to the northwest along a concealed thrust fault beneath the Cle Elum Ridge. The geologic basis for this rupture is a set of thrust faults along the northern flank of Manastash Ridge. One of the thrusts turns and follows Manastash Creek westward while another turns northward and becomes a right-lateral strike-slip fault beneath the Taneum monocline just south of Cle Elum. No paleoseismology or slip-rate data is available for these faults.

Type of Earthquake

M6.8 scenario earthquake modeled for the Cle Elum seismic zone is a shallow or crustal earthquake. Shallow quakes tend to be much more damaging than deep quakes of comparable magnitude (such as the deep M6.8 Nisqually earthquake in 2001). This is primarily because in deeper earthquakes, the seismic waves lose a majority of its energy by the time they reach the surface.

Aftershocks: Unlike deep earthquakes, which usually produce few or no aftershocks strong enough to be felt, a M6.8 shallow earthquake like the one in this scenario would likely be followed by many aftershocks, a few of which could be large enough to cause additional damage.

HAZUS Results for the Cle Elum Scenario

HAZUS was used to estimate the losses that could result from a M6.8 scenario earthquake on the Cle Elum seismic zone in Kittitas and Yakima counties. This event is expected to impact ten counties in Washington, with the most significant effects apparent in Yakima and Kittitas counties.

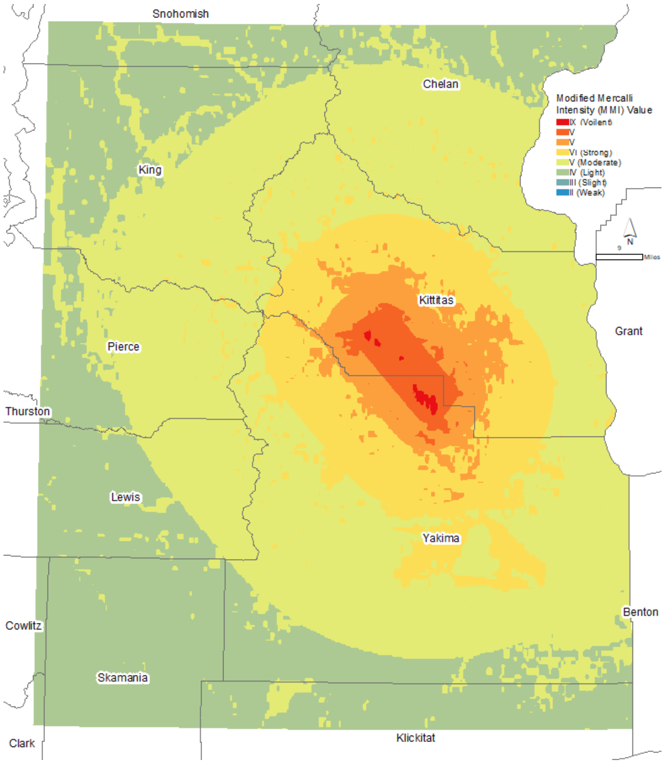


FIGURE AE 6: CLE ELUM SEISMIC ZONE MAGNITUDE 6.8 SCENARIO SHAKING INTENSITY

Summary of Significant Losses M6.8 Cle Elum Scenario Earthquake	
End-to-end length of fault (kilometers)	30
Magnitude (M) of scenario earthquake	6.8
Number of counties impacted	10
Total injuries (*severity 1, 2, 3, 4) at 2:00 PM	55
Total number of buildings extensively damaged	550
Total number of buildings completely damaged	75
Income losses in millions	$47
Displaced households	138
People requiring shelter (individuals)	110
Capital stock losses in millions	$215
Debris total in millions of tons	0.07
Truckloads of debris (25 tons per truckload)	2,600
People without power (Day 1)	1,516
People without potable water (Day 1)	1,058

Injuries: The estimated number of people injured in this scenario is low for all counties except Yakima and Kittitas. Although most of the injuries are not expected to be serious enough to require hospitalization, potentially life-threatening injuries are anticipated, particularly in Kittitas County. Several fatalities are also possible, particularly if the event occurs during the evening commute.

Damage: Buildings in all counties will sustain some damage; in most cases, the level of damage is expected to range from slight to moderate. Yakima and Kittitas counties will have the greatest number of damaged buildings. Most of these will be residential, although the damage estimates include many commercial and industrial buildings, especially unreinforced masonry structures. About 550 buildings are likely to be extensively damaged, and at least 74 are projected to collapse or to be in danger of collapse (complete damage). Kittitas County accounts for most of these.

Economic Losses Due to Damage: Capital stock losses are the direct economic losses associated with damage to buildings, including the cost of structural and non-structural damage, damage to contents, and loss of inventory. Yakima County accounts for the largest portion of the capital stock loss estimate (over $106 million), followed by Kittitas County ($94 million) and King County (about $9 million).

Income losses, including wage losses and loss of rental income due to damaged buildings, are also highest in Kittitas County ($23.4 million) and Yakima County (about $22.4 million).

Impact on Households and Schools: Displaced households occur primarily in Kittitas and Yakima counties—the majority in Kittitas, which also has the highest number of households without power or water following the earthquake. These two counties will have the highest numbers of individuals in need of shelter; and in Kittitas County, the earthquake is expected to affect the functionality of some schools.

Debris Removal: Following an earthquake, debris consisting of brick, wood, concrete, and steel will have to be removed and disposed of. In this scenario Kittitas, Yakima, and King counties will account for most of the debris (30,600 tons or 2,520 truckloads).

Estimates vs. Actual Damage: Although this M6.8 earthquake scenario was modeled using the best scientific information available, it represents a simplified version of expected ground motions. The damage resulting from an actual earthquake of similar magnitude is likely to be even more variable and will depend on the specific characteristics and environment of each affected structure.

Darrington-Devils Mountain Fault Zone Magnitude 7.1 Earthquake

Geologic Description

This M7.1 earthquake scenario is based on a 50 kilometer (31 mile)-long rupture of the Darrington–Devils Mountain fault zone between Mount Vernon and Darrington. This fault zone forms the northern boundary of the Everett basin and lies along a series of high-amplitude aeromagnetic anomalies that extend from the Cascade Mountains to Vancouver Island, B.C.

This fault zone was originally named the Devils Mountain fault for exposures on Devils Mountain near Mount Vernon, Washington, where it separates Mesozoic rocks from Tertiary deposits. Later, another segment, called the Darrington fault zone, was identified where northeast-trending faults juxtapose Mesozoic mélange against Eocene rocks near the town of Darrington. In 1994, the two zones were combined into the Darrington–Devils Mountain fault zone (DDMFZ).

LIDAR (light detection and ranging) mapping along this fault zone revealed several potential fault scarps. Trenches across scarps on Whidbey Island exposed faulted and folded glaciomarine drift. Mostly high-angle reverse faults (with a few normal faults and low-angle reverse faults), these display approximately 1 to 4.5 meters (3–15 feet) of vertical separation and about 2 meters (6.5 feet) of left-lateral displacement. Radiocarbon ages from these trenches show that the deformation likely occurred during two earthquakes: the first 1,100 to 2,200 years ago; the second 100 to 500 years ago. Three trenches excavated across a low scarp (less than 1 meter [3 feet] high) east of Mount Vernon exposed faulted glacial deposits and sheared bedrock, with vertical separation of approximately 0.5meter (1.6 feet). Flower structures and abrupt facies changes across faults suggest a component of lateral slip: trenches excavated parallel to faults exposed offset glacial channels and bedrock shears indicating right-lateral displacement of 1 to 3.5 meters (3–11.5 feet).

Type of Earthquake

The M7.1 scenario earthquake modeled for the Darrington–Devils Mountain fault zone is a shallow or crustal earthquake. Shallow earthquakes tend to be much more damaging than deep quakes of comparable magnitude (such as the deep M6.8 Nisqually earthquake in 2001). This is primarily because in deeper earthquakes, the seismic waves lose a majority of its energy by the time they reach the surface.

Aftershocks: Unlike deep earthquakes, which usually produce few or no aftershocks strong enough to be felt, a M7.1 shallow earthquake like the one in this scenario would likely be followed by many aftershocks, a few of which could be large enough to cause damage.

Other Earthquake Effects

Tsunamis: Some earthquakes may rupture a fault at the surface of the ground. If this fault offsets the floor of Puget Sound, it could generate a local tsunami.

Delta failures and landslides caused by the shaking may also create or amplify tsunamis. Geological and historical evidence shows that landslides and failures of the sediments in river deltas have generated tsunamis within Puget Sound in the past and will again in the future.

HAZUS Results for the Darrington-Devils Mountain Scenario

HAZUS was used to estimate the losses that could result from a M7.1 scenario earthquake on the Darrington–Devils Mountain fault zone in southern Skagit and northern Snohomish counties. Such an event is expected to impact fifteen counties in Washington, with the most significant effects apparent in Skagit and Snohomish counties, followed by King, Island, and Whatcom.

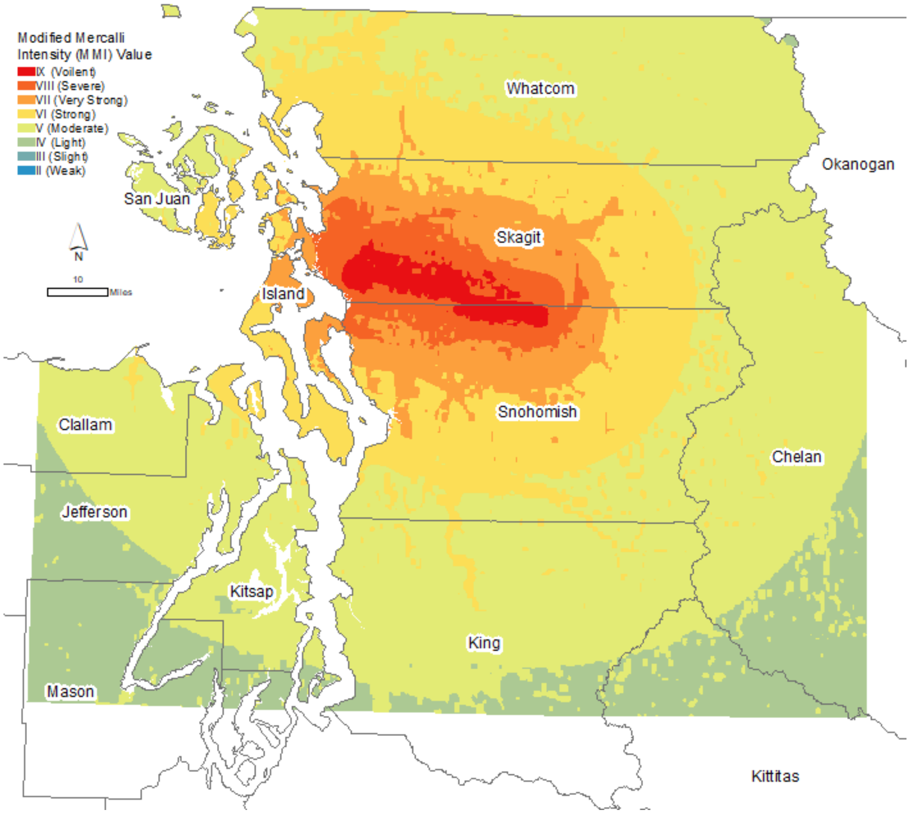


FIGURE AE 7: CLE ELUM SEISMIC ZONE MAGNITUDE 6.8 SCENARIO SHAKING INTENSITY

Summary of Significant Losses M7.1 Darrington Devils Mountain Scenario	
End-to-end length of fault (kilometers)	50
Magnitude (M) of scenario earthquake	7.1
Number of counties impacted	15
Total injuries (*severity 1, 2, 3, 4) at 2:00 PM	652
Total number of buildings extensively damaged	4,864
Total number of buildings completely damaged	1,439
Income losses in millions	$391
Displaced households	1,971

People requiring shelter (individuals)	1,448
Capital stock losses in millions	$1,866
Debris total in millions of tons	0.65
Truckloads of debris (25 tons per truckload)	25,920
People without power (Day 1)	10,176
People without potable water (Day 1)	29,697

Injuries: The number of people injured in this scenario is likely to be high, particularly if the earthquake occurs during the day. Skagit County is expected to suffer the highest number of casualties; many of the injuries will be serious enough to require hospitalization. Numerous fatalities are likely if the event occurs during the afternoon or early evening.

Damage: The earthquake will damage buildings in all the affected counties, but Skagit accounts for the greatest number. Nearly half of Skagit's building stock may be damaged; of these buildings, it is anticipated that more than 2,300 will be extensively damaged and approximately 750 completely damaged. After Skagit, the damage is greatest in Snohomish, Whatcom, and Island counties. Most of the damaged buildings will be residential, but commercial and industrial structures also account for a large part of the total in this scenario.

Economic Losses Due to Damage: Capital stock losses are the direct economic losses associated with damage to buildings, including the cost of structural and non-structural damage, damage to contents, and loss of inventory. Skagit County accounts for the largest portion of the capital stock loss estimate (over $677 million), followed by Snohomish (over $235 million), King (about $98.5 million), Island ($61.5 million), and Whatcom (about $46.5 million).

Income losses, including wage losses and loss of rental income due to damaged buildings, are also highest in Skagit County (more than $175 million) and Snohomish County (about $33 million).

Impact on Households and Schools: The number of people without power or water is expected to be highest in Skagit County. This county also accounts for most of the displaced households and individuals in need of shelter. Schools in Skagit County will be only 51percent functional on Day 1 after the earthquake.

Debris Removal: Following an earthquake, debris (brick, wood, concrete, and steel) must be removed and disposed of. Much of this will come from Skagit County (about 289,000 tons), with a significant portion from Snohomish, King, and Island counties (about 70,000 tons).

Estimates vs. Actual Damage: Although this M 7.1 earthquake scenario was modeled using the best scientific information available, it represents a simplified version of expected ground motions. The damage resulting from an actual earthquake of similar magnitude is likely to be even more variable and will depend on the specific characteristics and environment of each affected structure.

Darrington-Devils Mountain Fault Zone Western Section Magnitude 7.4 Earthquake

Geologic Description

The Darrington–Devils Mountain fault zone is in southern Skagit County and northern Snohomish County. It forms the northern boundary of the Everett basin and lies along a series of high-amplitude aeromagnetic anomalies that extend from the Cascade Mountains to Vancouver Island, B.C.

This fault zone was originally named the Devils Mountain fault for exposures on Devils Mountain near Mount Vernon, Washington, where it separates Mesozoic rocks from Tertiary deposits. Later, another segment, called the Darrington fault zone, was identified where northeast-trending faults juxtapose Mesozoic mélange against Eocene rocks near the town of Darrington. In 1994, the two zones were combined into the Darrington–Devils Mountain fault zone (DDMFZ).

LIDAR (light detection and ranging) mapping along this fault zone revealed several potential fault scarps. Trenches across scarps on Whidbey Island exposed faulted and folded glaciomarine drift. Mostly high-angle reverse faults (with a few normal faults and low-angle reverse faults), these display approximately 1 to 4.5 meters (3–15 feet) of vertical separation and about 2 meters (6.5 feet) of left- lateral displacement. Radiocarbon ages from these trenches show that the deformation likely occurred during two earthquakes: the first 1,100 to 2,200 years ago; the second 100 to 500 years ago. Three trenches excavated across a low scarp (less than 1 meter high) east of Mount Vernon exposed faulted glacial deposits and sheared bedrock, with vertical separation of approximately 0.5 meter (1.6 feet). Flower structures and abrupt facies changes across faults suggest a component of lateral slip: trenches excavated parallel to faults exposed offset glacial channels and bedrock shears indicating right-lateral displacement of 1 to 3.5 meters (3–11.5 feet).

Type of Earthquake

The M7.4 scenario earthquake modeled for the western section of the Darrington– Devils Mountain fault zone is a shallow or crustal earthquake. Shallow quakes tend to be more damaging than deep quakes of comparable magnitude (such as the deep M6.8 Nisqually earthquake in 2001). This is primarily because in deeper earthquakes, the seismic waves lose a majority of its energy by the time they reach the surface.

Aftershocks: Unlike deep earthquakes, which usually produce few or no aftershocks strong enough to be felt, a M7.4 shallow earthquake like the one in this scenario would likely be followed by many aftershocks, a few of which could be large enough to cause additional damage.

HAZUS Results for the Darrington-Devils Mountain (West) Scenario

HAZUS was used to estimate the losses that could result from a M7.4 scenario earthquake on the western section of the Darrington–Devils Mountain fault zone in southern Skagit County. Such an event is expected to impact twelve counties in Washington, with the most significant effects apparent in Skagit, Snohomish, and Island counties.

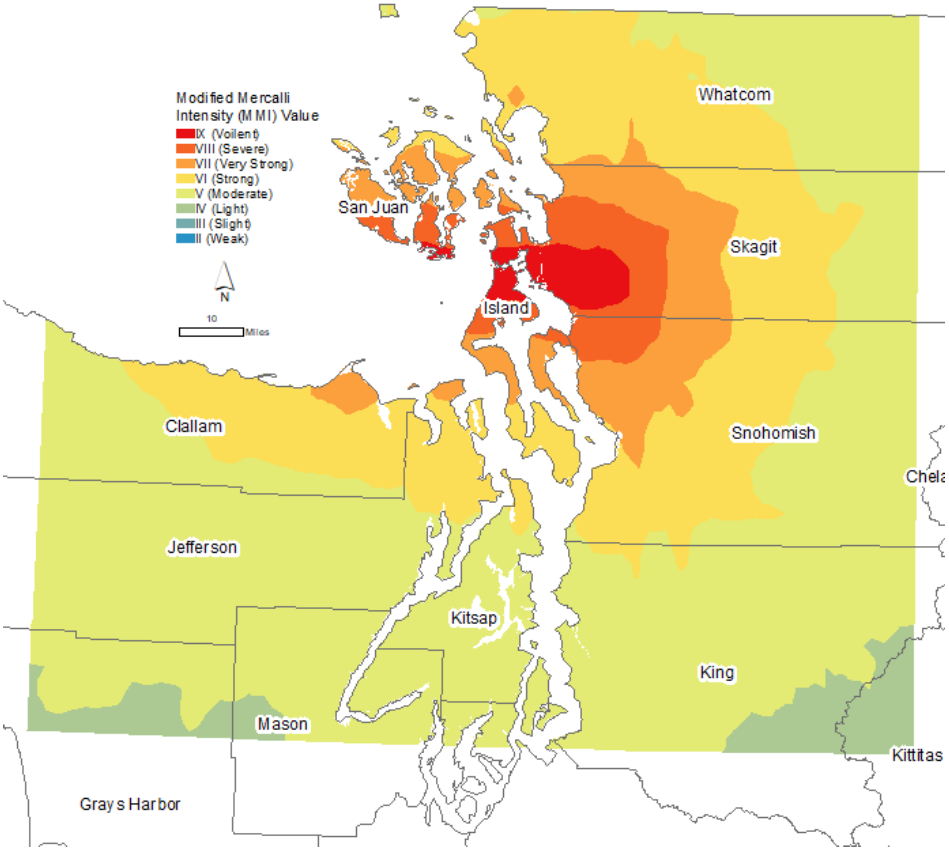


Figure AE 8: Darrington-Devils Mountain Fault Zone Western Section Magnitude 7.4 Earthquake Scenario Shaking Intensity

Summary of Significant Losses M7.4 Darrington Devils Mountain (West) Scenario	
End-to-end length of fault (kilometers)	80
Magnitude (M) of scenario earthquake	7.4
Number of counties impacted	12
Total injuries (*severity 1, 2, 3, 4) at 2:00 PM	1,119
Total number of buildings extensively damaged	4,864
Total number of buildings completely damaged	1,439
Income losses in millions	$391
Displaced households	1,971
People requiring shelter (individuals)	1,448
Capital stock losses in millions	$1,866
Debris total in millions of tons	0.65
Truckloads of debris (25 tons per truckload)	25,920
People without power (Day 1)	10,176

People without potable water (Day 1)	29,697

Injuries: The number of people injured in this scenario is likely to be high, particularly if the earthquake occurs during the day. Skagit County is expected to suffer the highest number of casualties. Although the majority of the injured will not require hospitalization, numerous serious and potentially life-threatening injuries are anticipated. Many fatalities are also likely if the event occurs during the afternoon or early evening; more than 50 fatalities are estimated for Skagit County.

Damage: The earthquake will damage thousands of buildings in all the affected counties, but the numbers are highest in Skagit (29,448), Snohomish (16,471), and Island (12,477) counties. In Skagit County, 3,300 buildings will be extensively damaged and more than 1,100 will collapse or be in danger of collapse (complete damage). Most of the damaged buildings will be residential, but commercial and industrial structures also account for a large part of the total. Many unreinforced masonry structures will experience partial to full collapse.

Economic Losses Due to Damage: Capital stock losses are the direct economic losses associated with damage to buildings, including the cost of structural and non-structural damage, damage to contents, and loss of inventory. Skagit County accounts for over $998 million of the total loss estimate, followed by Island (almost $277 million), Snohomish ($262.5 million) and King (over $135 million).

Income losses, including wage losses and loss of rental income due to damaged buildings, are highest in Skagit (nearly $259 million), Island ($55 million), and Snohomish (more than $39 million) counties.

Impact on Households and Schools: The number of people without power or water may be highest in Skagit County. This county also accounts for most of the displaced households and individuals in need of shelter. Schools in Skagit County will be only 40percent functional on Day one following the earthquake.

Debris Removal: After an earthquake, debris (brick, wood, concrete, and steel) must be removed and disposed of. Much of this will come from Skagit County (about 429,000 tons), along with Island and Snohomish counties (168,000 tons combined).

Estimates vs. Actual Damage: Although this M7.4 earthquake scenario was modeled using the best scientific information available, it represents a simplified version of expected ground motions. The damage resulting from an actual earthquake of similar magnitude is likely to be even more variable and will depend on the specific characteristics and environment of each affected structure.

Hite Fault Zone Magnitude 6.8 Earthquake

Geologic Description

The M6.8 scenario earthquake for the region of Walla Walla is based on an approximately 30 kilometer (19-mile)-long rupture on the Hite fault system. The Hite fault system is a zone of faults that parallels the northeast-trending flank of the Blue Mountains in Oregon and Washington. This fault system is thought to be the suture between the stable North American craton to the east and accreted terranes to the west. The fault zone is about 1.5 kilometers (1-mile) wide and consists of fault strands with normal, left-lateral, and right-lateral strike-slip motion. No evidence for Quaternary or recent activity on the Hite fault exists at this time. No detailed fault- slip data exist for the Hite fault.

Type of Earthquake

The M6.8 scenario earthquake modeled for the Hite fault zone is a shallow or crustal earthquake. Shallow quakes tend to be much more damaging than deep quakes of comparable magnitude (such as the deep M6.8 Nisqually earthquake in 2001). This is primarily because in deeper earthquakes, the seismic waves lose a majority of its energy by the time they reach the surface.

Aftershocks: Unlike deep earthquakes, which usually produce few or no aftershocks strong enough to be felt, a M6.8 shallow earthquake like the one in the Walla Walla (Hite fault) scenario may be followed by numerous aftershocks, a few of which could be large enough to cause additional damage.

HAZUS Results for the Walla Walla (Hite Fault) Scenario

HAZUS was used to estimate the losses that could result from a M6.8 scenario earthquake on the Hite fault zone in the southeastern quarter of Walla Walla County. Such an event is expected to impact ten counties in Washington, with the most significant effects in Walla Walla County.

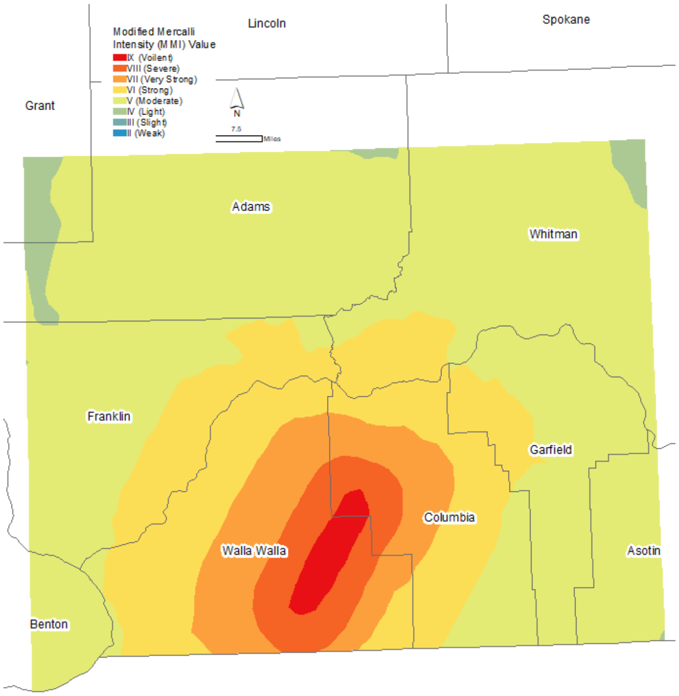


FIGURE AE 9: HITE FAULT ZONE MAGNITUDE 6.8 EARTHQUAKE SCENARIO SHAKING INTENSITY

Summary of Significant Losses M6.8 Walla Walla (Hite Fault) Scenario Earthquake	
End-to-end length of fault (kilometers)	31
Magnitude (M) of scenario earthquake	6.8
Number of counties impacted	10
Total injuries (*severity 1, 2, 3, 4) at 2:00 PM	795
Total number of buildings extensively damaged	2,700
Total number of buildings completely damaged	1,354
Income losses in millions	$265
Displaced households	1,321
People requiring shelter (individuals)	1,011
Capital stock losses in millions	$856
Debris total in millions of tons	0.49
Truckloads of debris (25 tons per truckload)	19,480
Households without power (Day 1)	1,743
Households without potable water (Day 1)	19,321

Injuries: Injuries are most likely in Walla Walla County. This county alone accounts for the majority of the scenario’s injuries and estimated casualties. While most of the injuries will not be life-threatening, many will require hospitalization and at least several dozen may be life-threatening if not treated promptly. Some fatalities are also expected, possibly as many as 50. The number of injuries and fatalities tends to be higher if an earthquake occurs during or at the end of the business day.

Damage: The earthquake is expected to damage buildings in all the surrounding counties, although for some counties (such as Garfield and Whitman), the damage is anticipated to be minimal. Walla Walla County will have the highest number of damaged buildings (over 16,000). Of these, more than 2,600 may be extensively damaged and more than 1,300 could suffer collapse or be in danger of collapsing (complete damage). While damage to most buildings in Columbia and Franklin counties will be slight to moderate, extensive damage is expected in some cases (primarily in Columbia County). Most of the damaged buildings will be residential or commercial structures, although other types of buildings, such as industrial facilities, will also be affected.

Economic Losses Due to Damage: Capital stock losses are the direct economic losses associated with damage to buildings, including the cost of structural and non-structural damage, damage to contents, and loss of inventory. Walla Walla County accounts for the largest portion of the capital stock loss estimate (over $833 million).

Income losses, including wage losses and loss of rental income due to damaged buildings, are also highest in Walla Walla County (over $261 million).

Impact on Households and Schools: Walla Walla County accounts for nearly all the estimated displaced households and individuals in need of shelter. Schools in Walla Walla County will be only 42percent functional on Day one following the earthquake.

Debris Removal: Following an earthquake, debris consisting of brick, wood, concrete, and steel must be removed and disposed of. Most of this will come from Walla Walla County (about 482,000 tons).

Estimates vs. Actual Damage: Although this M6.8 earthquake scenario was modeled using the best scientific information available, it represents a simplified version of expected ground motions. The damage resulting from an actual earthquake of similar magnitude is likely to be even more variable and will depend on the specific characteristics and environment of each affected structure.

Lake Creek-Boundary Creek Fault Zone Magnitude 6.8 Earthquake

Geologic Description

The M6.8 earthquake scenario for the Lake Creek– Boundary Creek fault zone is based on a 30 kilometer (19 mile)-long rupture of the fault between Lake Crescent and east Port Angeles, Washington. The Lake Creek–Boundary Creek fault zone is one of three east-west-trending, north-dipping fault zones along the north flank of the Olympic Mountains. The fault cuts Eocene and older rocks; where visible at the surface, the Paleocene Crescent Formation along the north side of the fault is faulted against younger Eocene sedimentary rocks (Hoko River Formation) south of the fault, suggesting reverse motion on the fault.

LIDAR (light detection and ranging) images reveal a 30 kilometer (19 mile)-long topographic lineament following the trace of the Lake Creek–Boundary Creek fault. Along parts of the lineament, scarps about 2 meters (7 feet) high face opposite directions, suggesting a lateral component of movement along the fault. Five trenches excavated across the scarp exposed faulted and folded glacial deposits: one trench contains basalt bedrock thrust over Quaternary glacial deposits; however, most of the faults have normal displacement. Flower structures suggest a significant but unknown amount of lateral displacement. Radiocarbon ages from faulted soils and scarp- derived colluvium suggest two earthquakes between 2,000 and 600 years ago. Stratigraphic relations and radiocarbon ages in one trench suggest an earlier earthquake that was less than 5,000 years ago.

Type of Earthquake

The M6.8 scenario earthquake modeled for the Lake Creek–Boundary Creek fault zone is a shallow or crustal earthquake. Shallow quakes tend to be much more damaging than deep quakes of comparable magnitude (such as the deep M6.8 Nisqually earthquake in 2001). This is primarily because in deeper earthquakes, the seismic waves lose a majority of its energy by the time they reach the surface.

Aftershocks: Unlike deep earthquakes, which usually produce few or no aftershocks strong enough to be felt, a M6.8 shallow earthquake like the one in this scenario would likely be followed by many aftershocks, a few of which could be large enough to cause additional damage.

HAZUS Results for the Lake Creek-Boundary Creek Scenario

HAZUS was used to estimate the losses that could result from a M6.8 earthquake on the Lake Creek– Boundary Creek fault zone in Clallam County. Such an event is expected to impact 14 counties in Washington, with the most significant effects apparent in Clallam County.

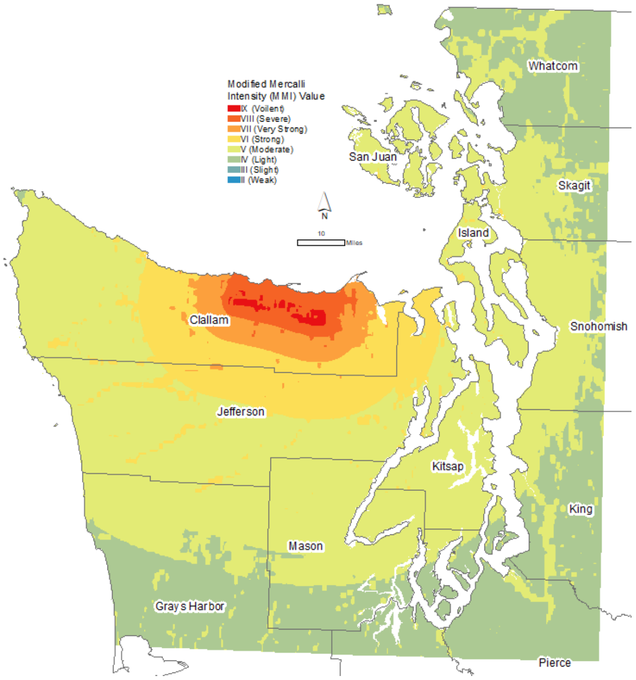


FIGURE AE 10: LAKE CREEK-BOUNDARY CREEK FAULT ZONE MAGNITUDE 6.8 SCENARIO SHAKING INTENSITY

Summary of Significant Losses M6.8 Lake Creek Boundary Creek Scenario Earthquake	
End-to-end length of fault (kilometers)	30
Magnitude (M) of scenario earthquake	6.8
Number of counties impacted	14
Total injuries (*severity 1, 2, 3, 4) at 2:00 PM	253
Total number of buildings extensively damaged	1,612
Total number of buildings completely damaged	407
Income losses in millions	$128
Displaced households	460
People requiring shelter (individuals)	283
Capital stock losses in millions	$518
Debris total in millions of tons	0.19
Truckloads of debris (25 tons per truckload)	7,680
People without power (Day 1)	9,095
People without potable water (Day 1)	544

Injuries: Several hundred people are expected to be injured in this earthquake, most in Clallam County. Fewer injuries are anticipated in other counties, and most of these are not expected to require immediate medical attention. In Clallam County, many of the injured will require hospitalization, and some injuries will be life-threatening. Some fatalities are also likely, particularly if the event occurs in the afternoon or during the evening commute.

Damage: The earthquake will damage some buildings in all the affected counties, but the greatest number will be in Clallam County. More than half of this county's building stock may suffer some damage; of these buildings, more than 1,600 could be extensively damaged and over 400 might collapse or be in danger of collapse. The damage to buildings in other counties will range from slight to moderate. In all counties, the majority of damaged buildings will be residential, but commercial and industrial structures will also make up a sizable part of the total. Many unreinforced masonry structures will most likely collapse.

Economic Losses Due to Damage: Capital stock losses are the direct economic losses associated with damage to buildings, including the cost of structural and non-structural damage, damage to contents, and loss of inventory. Clallam County accounts for the largest portion of the capital stock loss estimate (over $445 million), followed by King (about $31 million), Snohomish (over $9 million), Kitsap ($7.5 million), and Whatcom ($5.6 million).

Income losses, including wage losses and loss of rental income due to damaged buildings, are also highest in Clallam County (over $122 million) and King County (about $2.5 million).

Impact on Households and Schools: The number of people without power or water will be highest in Clallam County. This county also accounts for most of the displaced households and individuals in need of shelter. In Clallam County, schools will be only 49percent functional on Day one following the earthquake.

Debris Removal: Following an earthquake, debris consisting of brick, wood, concrete, and steel will have to be removed and disposed of. Much of this will come from Clallam County (182,000 tons). Together, King, Kitsap, Skagit, Snohomish and Jefferson counties account for about 9,000 tons.

Estimates vs. Actual Damage: Although this M6.8 earthquake scenario was modeled using the best scientific information available, it represents a simplified version of expected ground motions. The damage resulting from an actual earthquake of similar magnitude is likely to be even more variable and will depend on the specific characteristics and environment of each affected structure.

Mill Creek Fault Zone Magnitude 7.1 Earthquake

Geologic Description

The M7.1 Mill Creek earthquake scenario is based on a 57 kilometer (35 mile)-long rupture of the fault along the northern flank of Toppenish Ridge. Toppenish Ridge is an anticline in the southern part of the Yakima fold and thrust belt, an east–west- trending set of anticlinal ridges and synclinal valleys with associated thrust faults that deform late Miocene and younger rocks. The Mill Creek fault— mapped as a thrust fault—follows the northern flank of Toppenish Ridge for 65 kilometers (40 miles). A young fault scarp is associated with the Mill Creek fault and numerous normal faults near the crest of the ridge are associated with bending-moment folding and faulting.

Paleoseismology of natural exposures and trenches show that the Mill Creek thrust along the northern flank of Toppenish Ridge dips between 9° and 15° to the south. Fault scarp excavations exposed a gently dipping thrust fault that places late Miocene volcanic rocks of the Columbia River Basalt Group over late Pleistocene sand and gravels. Ages of soils that are overridden by the Mill Creek fault limit the youngest earthquake to between 7,490 ±70 and 5,690 ±390 C14 years BP. The USGS Fault and Fold Database lists the Mill Creek fault as having a slip rate of less than 0.2 millimeters/year.

Type of Earthquake

The M7.1 scenario earthquake modeled for the Mill Creek fault zone is a shallow or crustal earthquake. Shallow earthquakes tend to be much more damaging than deep quakes of comparable magnitude (such as the deep M6.8 Nisqually earthquake in 2001). This is primarily because in deeper earthquakes, the seismic waves lose a majority of its energy by the time they reach the surface.

Aftershocks: Unlike deep earthquakes, which usually produce few or no aftershocks strong enough to be felt, a M7.1 shallow earthquake like the one in this scenario would likely be followed by many aftershocks, a few of which could be large enough to cause additional damage.

HAZUS Results for the Mill Creek Scenario

HAZUS was used to estimate the losses that could result from a M7.1 scenario earthquake on the Mill Creek fault zone in Yakima County. Such an event is expected to impact sixteen counties in Washington, with the most significant effects apparent in Yakima County, followed by Benton and Klickitat counties.

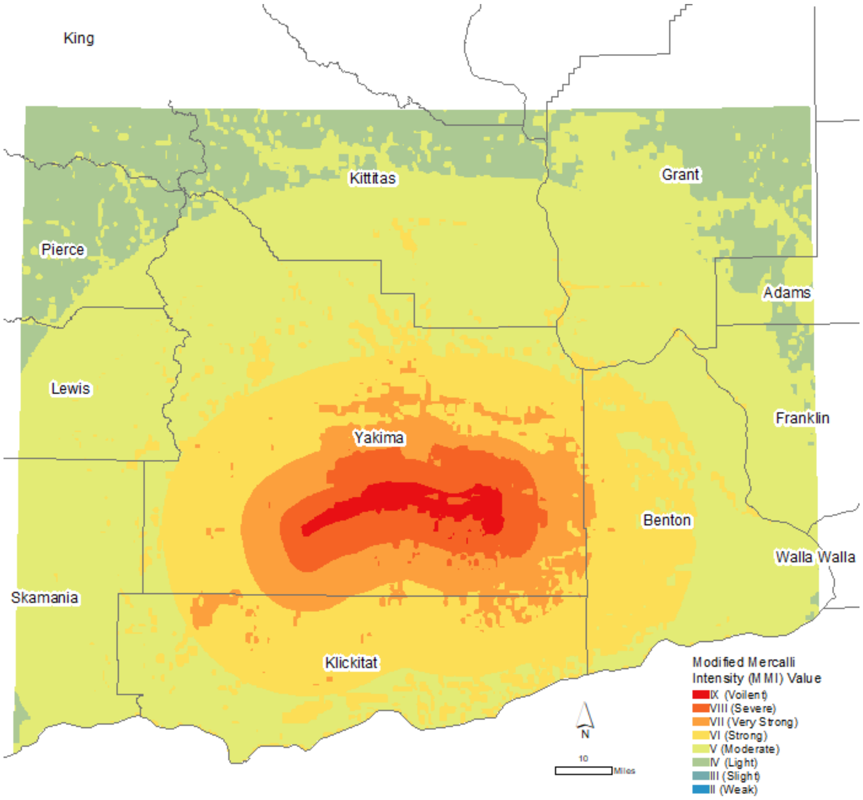


FIGURE AE 11: MILL CREEK FAULT ZONE MAGNITUDE 7.1 EARTHQUAKE SCENARIO SHAKING INTENSITY

Summary of Significant Losses M7.1 Mill Creek Scenario Earthquake	
End-to-end length of fault (kilometers)	55
Magnitude (M) of scenario earthquake	7.1
Number of counties impacted	16
Total injuries (*severity 1, 2, 3, 4) at 2:00 PM	191
Total number of buildings extensively damaged	1,678
Total number of buildings completely damaged	297
Income losses in millions	$102
Displaced households	287
People requiring shelter (individuals)	325
Capital stock losses in millions	$339
Debris total in millions of tons	0.17
Truckloads of debris (25 tons per truckload)	6,880
People without power (Day 1)	1,135
People without potable water (Day 1)	9,440

Injuries: The number of people injured in this scenario will be highest in Yakima County. While most of these injuries will not be life-threatening, some more serious injuries and fatalities are expected, especially if the earthquake occurs during the business day. Residents of Benton and Klickitat counties are also likely to experience injuries, but few of these are expected to require hospitalization.

Damage: The earthquake will damage buildings in all the affected counties. For many, only a few dozen or a few hundred buildings will be affected, and the damage is expected to be slight to moderate. In Yakima County, however, thousands of buildings will suffer damage; over 1,700 buildings are expected to be extensively damaged. Hundreds of buildings will collapse or be in danger of collapsing. Commercial and industrial buildings account for a large part of the total, but damaged residential structures will also be numerous. Unreinforced masonry buildings may experience collapse. After Yakima, the extent of damage will be greatest in Benton County.

Economic Losses Due to Damage: Capital stock losses are the direct economic losses associated with damage to buildings, including the cost of structural and non-structural damage, damage to contents, and loss of inventory. Yakima County accounts for the largest portion of the capital stock loss estimate (nearly $314 million), followed by Benton County (over $23.5 million).

Income losses, including wage losses and loss of rental income due to damaged buildings, are also highest in Yakima County (over $99 million) and Benton County (about $3 million).

Impact on Households and Schools: The number of people without power or water will be highest in Yakima County. This county also accounts for most of the displaced households and individuals in need of shelter. Schools in Yakima County will be only 81percent functional on Day 1 following the earthquake.

Debris Removal: Following an earthquake, debris consisting of brick, wood, concrete, and steel will have to be removed and disposed of. Much of this will come from Yakima County (169,000 tons) and Benton County (4,000 tons).

Estimates vs. Actual Damage: Although this M7.1 earthquake scenario was modeled using the best scientific information available, it represents a simplified version of expected ground motions. The damage resulting from an actual earthquake of similar magnitude is likely to be even more variable and will depend on the specific characteristics and environment of each affected structure.

Nisqually Fault Zone Magnitude 7.2 Earthquake

Geologic Description

This scenario is based on a M7.2 deep earthquake centered below the Nisqually delta. Deep earthquakes—also called intraplate or Wadati-Benioff zone earthquakes—are common in western Washington. Over the last 65 years, the largest of these deep earthquakes occurred between Olympia and Seattle in 1949 (M7.0), 1965 (M6.5), and 2001 (M6.8).

Intraplate earthquakes usually are the result of normal faulting within the upper part of a subducting oceanic plate and typically are not followed by large aftershocks. Beneath western Washington, the depth range of deep earthquakes begins near 30 kilometers (19 miles) and continues downward to about 60 kilometers (37 miles). This range is where all the damaging deep earthquakes have been located. In some places, notably central and northern Puget Sound, a few deep earthquake events have been recorded, but their magnitudes tend to be small. The distribution of deep earthquake allows seismologists to map the surface of the subducting Juan de Fuca plate as it descends into the mantle below western Washington.

Two mechanisms are often cited as the cause of these earthquakes:

1. The subducting plate is bent by gravity as it descends into the mantle, and bending-moment forces cause normal faults to rupture in the upper part of the down-going slab
2. Dehydration and metamorphism of minerals in the down-going slab cause the plate to shrink and become denser, in turn causing stresses to build up that pull the plate apart.

Worldwide, deep earthquakes can reach M7.5 or greater. For example, a M7.5 deep earthquake beneath Oaxaca, Mexico, occurred on September 30, 1999. Our historical record of these earthquakes in northwestern Washington suggests an average recurrence of 30 years for a magnitude 6.5 or greater deep earthquake.

Type of Earthquake

Like the M6.8 Nisqually earthquake in 2001, the magnitude 7.2 earthquake modeled in this scenario is a deep earthquake. In relative terms, deep quakes tend to be less damaging than shallow quakes of comparable magnitude; this is primarily because in deeper earthquakes, the seismic waves lose a majority of its energy by the time they reach the surface. Nevertheless, a deep earthquake of this magnitude will cause damage. The shaking from a deep earthquake is also likely to be felt over a much larger area than shaking caused by a shallow quake.

Aftershocks: Unlike shallow earthquakes, which usually produce numerous aftershocks, a M7.2 deep earthquake like the one in this scenario is not likely to be followed by aftershocks strong enough to be felt.

HAZUS Results for the Nisqually (Olympia) Scenario

HAZUS was used to estimate the losses that could result from a M7.2 earthquake on the Nisqually fault zone beneath Pierce and Thurston counties. Such a scenario is expected to impact seventeen counties in Washington, with the most significant effects apparent in King, Pierce, and Thurston counties.

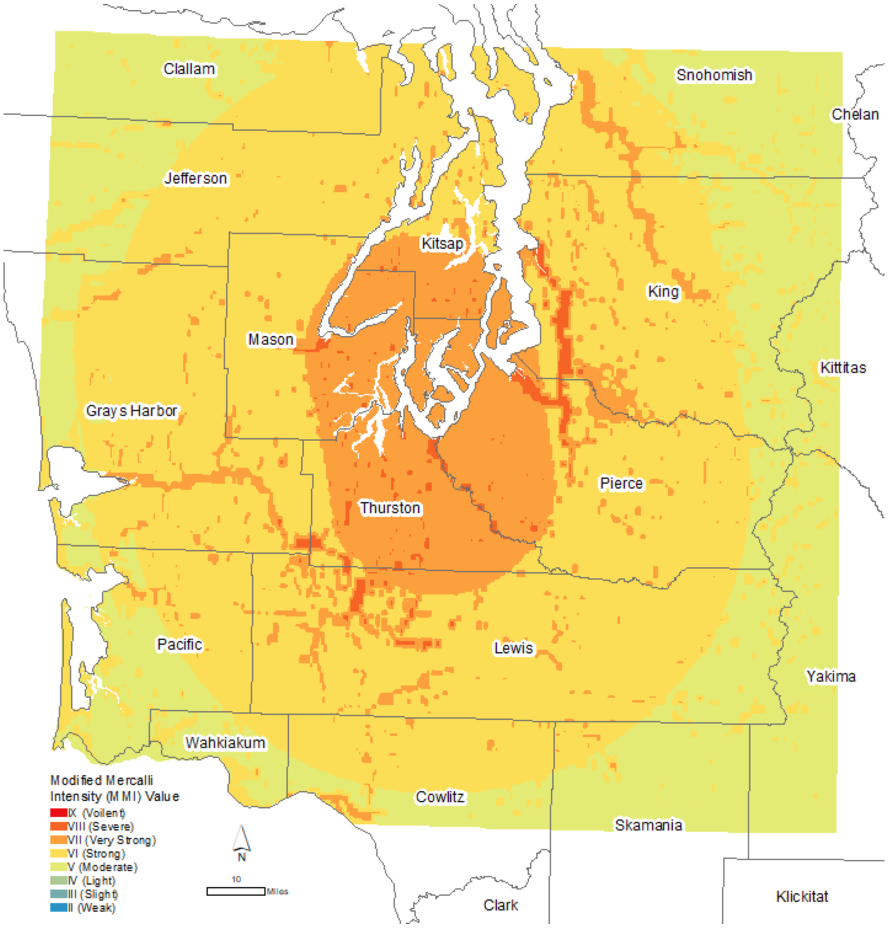


FIGURE AE 12: NISQUALLY FAULT ZONE MAGNITUDE 7.2 EARTHQUAKE SCENARIO SHAKING INTENSITY

Summary of Significant Losses M7.2 Nisqually Scenario Earthquake	
End-to-end length of fault (kilometers)	38
Magnitude (M) of scenario earthquake	7.2
Number of counties impacted	17
Total injuries (*severity 1, 2, 3, 4) at 2:00 PM	1,750
Total number of buildings extensively damaged	6,026
Total number of buildings completely damaged	547
Income losses in millions	$1,015
Displaced households	3,258

People requiring shelter (individuals)	2,015
Capital stock losses in millions	$5,325
Debris total in millions of tons	1.43
Truckloads of debris (25 tons per truckload)	57,040
People without potable water (Day 1)	45,916

Injuries: The number of people injured in this scenario is likely to be high, particularly if the earthquake occurs during or at the end of the business day. King County is expected to have the highest number of injured people, followed by Pierce and Thurston counties. Many of the injuries will be serious enough to require hospitalization, and some may be life-threatening if not treated promptly. Numerous fatalities are likely if the event occurs during the afternoon or early evening.

Damage: The earthquake will damage buildings in all the affected counties, but King, Pierce, and Thurston account for the highest number (over 200,000). Of these buildings, more than 1,900 in King County will be extensively damaged, 1,633 in Pierce County, and 1,140 in Thurston. In addition, several hundred buildings will collapse or be in imminent danger of collapse (complete damage). Most of the damaged buildings will be residential, but commercial and industrial structures also account for a large part of the total.

Economic Losses Due to Damage: Capital stock losses are the direct economic losses associated with damage to buildings, including the cost of structural and non-structural damage, damage to contents, and loss of inventory. King County accounts for the largest portion of the capital stock loss estimate (over $3.7 billion), followed by Pierce (over $1.5 billion), and Thurston (about $811 million).

Income losses, including wage losses and loss of rental income due to damaged buildings, are also highest in King County ($726 million), Pierce County ($292 million), and Thurston County (over $154 million).

Impact on Households and Schools: The number of people without water will be highest in King, Pierce, and Thurston counties. These counties also account for most of the displaced households and individuals in need of shelter. The functionality of schools will be most affected in Thurston and Pierce counties.

Debris Removal: Following an earthquake, debris consisting of brick, wood, concrete, and steel must be removed and disposed of. Much of this will come from King County (about 681,000 tons), with a significant portion from Pierce, Thurston, Lewis, and Snohomish counties (about 628,000 tons).

Estimates vs. Actual Damage: Although the M6.8 earthquake scenario for the Nisqually fault zone was modeled using the best scientific information available, it represents a simplified version of expected ground motions. The damage resulting from an actual earthquake of similar magnitude is likely to be even more variable and will depend on the specific characteristics and environment of each affected structure.

Olympia Fault Magnitude 5.7 Earthquake

Geologic Description

The Olympia fault is a gravitational and aeromagnetic anomaly about 80 kilometers (50 miles) long that separates the sedimentary deposits of the Tacoma basin from the basalt of the Black Hills uplift. This structure is shown in gravitational mapping of 1965, but without comment. In 1985, it was mapped from Shelton (near the Olympic foothills) southeast to Olympia (under the state legislature), directly under the town of Rainier, to a point due east of the Doty fault, and apparently marking the northeastern limit of a band of southeast-striking faults in the Centralia– Chehalis area. It was labeled structure L and interpreted it as simple folds in Eocene bedrock; though in 1998 a geologist saw enough similarity with the Seattle fault to speculate that it is a thrust fault. Others observed the straight boundaries and interpreted these as evidence of structural control, but refrained from calling it a fault—their model of the Black Hills uplift is analogous with their wedge model of the Seattle uplift, but in the opposite direction. (If entirely analogous, then a roof duplex might also apply, and the Olympia fault would be a reverse fault similar to the Tacoma fault.)

The Olympia fault is identified by high amplitude lineaments on gravity, magnetic, and LIDAR (light detection and ranging) data. New imaging data across this southeast-striking structure identify faulting of shallow (<60 meters; 197 feet) post-glacial sediments by near-vertical faults, one showing opposite senses of displacement on different beds, suggesting more than one fault is present with some strike-slip motion. The strike of the faults imaged on the seismic profiles aligns with LIDAR lineations on nearby land. It is not certain that these shallow faults are the surface expression of a deep-seated fault rather than minor bending-moment faults, but the documentation of faults near the structure emphasizes the seismic potential of faults beneath the south Puget Lowland. Regional seismic surveys have not been acquired across this structure, in part because no regional waterways cross the area.

Type of Earthquake

The M5.7 scenario earth-quake modeled for the Olympia fault zone is a shallow or crustal earthquake. Shallow quakes tend to be much more damaging than deep quakes of comparable magnitude (such as the deep M6.8 Nisqually earthquake in 2001). This is primarily because in deeper earthquakes, the seismic waves lose a majority of its energy by the time they reach the surface.

Aftershocks: Unlike deep earthquakes, which usually produce few or no aftershocks strong enough to be felt, shallow earthquakes are likely to be followed by many aftershocks, a few of which could be large enough to cause additional damage.

HAZUS Results for the Olympia Fault Scenario

HAZUS was used to estimate the losses that could result from a M5.7 earthquake on the Olympia fault beneath Thurston County. Such a scenario is expected to impact five counties in Washington, with the most significant effects apparent in Thurston, Mason and Pierce counties.

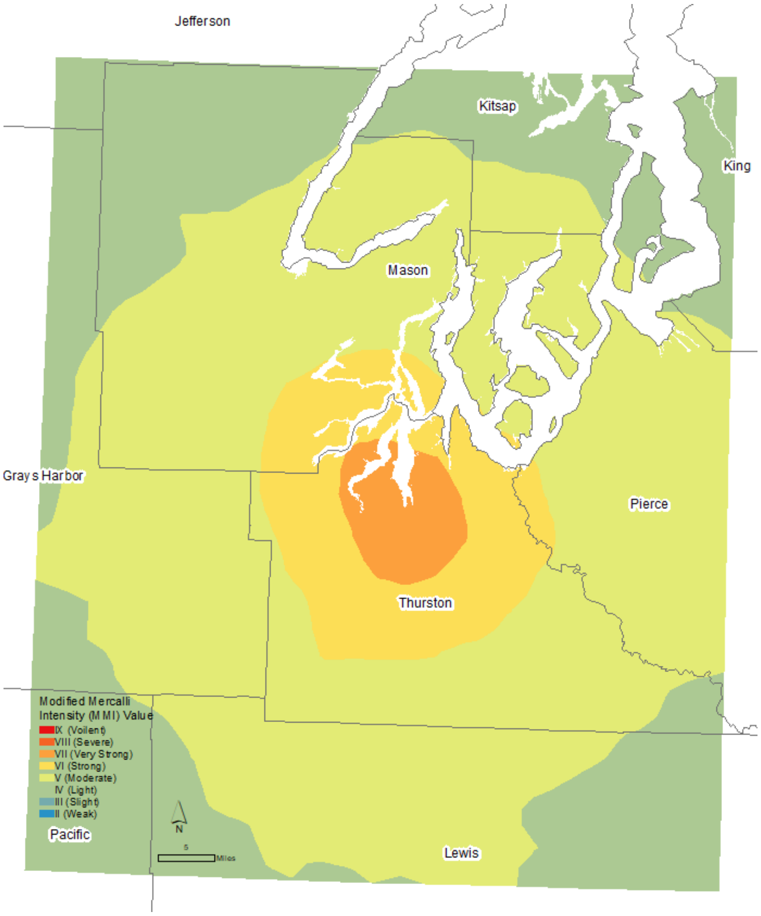


FIGURE AE 13: OLYMPIA FAULT MAGNITUDE 5.7 EARTHQUAKE SCENARIO SHAKING INTENSITY

Summary of Significant Losses in M5.7 Olympia Fault Scenario Earthquake	
End-to-end length of fault (kilometers)	7
Magnitude (M) of scenario earthquake	5.7
Number of counties impacted	5
Total injuries (*severity 1, 2, 3, 4) at 2:00 PM	94
Total number of buildings extensively damaged	388
Total number of buildings completely damaged	29
Income losses in millions	$70
Displaced households	242
People requiring shelter (individuals)	139
Capital stock losses in millions	$426

Debris total in millions of tons	0.09
Truckloads of debris (25 tons per truckload)	3,480
People without potable water (Day 1)	274

Injuries: The estimated number of people injured in this scenario is highest if the earthquake occurs during or at the end of the business day and the majority of the injuries are expected to occur in Thurston County. While most of these injuries may not require hospitalization, some injuries will be more serious and a few may be life-threatening if not treated promptly. Several fatalities are also likely if the event occurs during the business day or evening commute.

Damage: The earthquake will damage buildings in all the affected counties, but the highest number by far will be in Thurston County (20,838). For most counties, the damage will be slight to moderate, but in Thurston County, nearly 400 buildings will be extensively damaged and at least 28 buildings will collapse or be in imminent danger of collapse (complete damage). Most of the damaged buildings will be residential, but commercial and industrial structures also account for a large part of the total.

Economic Losses Due to Damage: Capital stock losses are the direct economic losses associated with damage to buildings, including the cost of structural and non-structural damage, damage to contents, and loss of inventory. Thurston County accounts for the largest portion of the capital stock loss estimate (over $400 million), followed by Pierce County (about $12.5 million) and Mason County (more than $5 million).

Income losses, including wage losses and loss of rental income due to damaged buildings, are also highest in Thurston County (over $68.7 million) and Pierce County (about $4.4 million).

Impact on Households and Schools: The number of people without water will be highest in Thurston County. This county also accounts for all the displaced households and individuals in need of shelter. The functionality of schools is likely to be affected only in Thurston County.

Debris Removal: Following an earthquake, debris consisting of brick, wood, concrete, and steel must be removed and disposed of. Much of this will come from Thurston County (about 85,000 tons), with Pierce and Mason contributing only 1,000 tons each.

Estimates vs. Actual Damage: Although this M5.7 earthquake scenario was modeled using the best scientific information available, it represents a simplified version of expected ground motions. The damage resulting from an actual earthquake of similar magnitude is likely to be even more variable and will depend on the specific characteristics and environment of each affected structure.

Saddle Mountain Fault Zone Magnitude 7.4 Earthquake

Geologic Description

The M7.4 earthquake scenario on the Saddle Mountain fault zone is modeled on a 100 kilometer (62 mile)-long rupture on the Saddle Mountain fault. This fault is an east–west-trending thrust fault mapped along the northern flank of Saddle Mountain, an anticline in the northern part of the Yakima fold and thrust belt. This fold and thrust belt is a structure- tectonic province of the Columbia Basin province and formed as the result of generally north–south contraction. The Yakima fold and thrust belt is a series of generally East–West trending anticlinal ridges and synclinal valleys.

Folding and faulting in the Yakima fold and thrust belt deforms middle to late Miocene Columbia River basalts and late Miocene to Pliocene sediments on top of the basalts, suggesting that deformation began in the mid-late Miocene or younger. The Saddle Mountain fault is a south-dipping thrust fault that cuts the north limb of the Saddle Mountain anticline. Recent deformation is documented along the fault in the Smyrna Bench area. Evidence for quaternary faulting includes late Pleistocene to Holocene faulting along a graben adjacent to the Saddle Mountain fault and beheaded streams, suggesting recent movement. Geologists have found 6.5 meters (21 feet) of displacement across a fault in the last 40,000 to 20,000 years, yielding a slip rate of 0.16 to 0.33 millimeters per year.

Type of Earthquake

The M7.4 scenario earthquake modeled for the Saddle Mountain fault zone is a shallow or crustal earthquake. Shallow quakes tend to be much more damaging than deep quakes of comparable magnitude (such as the deep M6.8 Nisqually earthquake in 2001). This is primarily because in deeper earthquakes, the seismic waves lose a majority of its energy by the time they reach the surface.

Aftershocks: Unlike deep earthquakes, which usually produce few or no aftershocks strong enough to be felt, a M7.4 shallow earthquake like the one in this scenario would likely be followed by many aftershocks, a few of which could be large enough to cause additional damage.

HAZUS Results for the Saddle Mountain Scenario

HAZUS was used to estimate the losses that could result from a M7.4 scenario earthquake on the Saddle Mountain fault zone, which crosses portions of Kittitas, Grant, Adams, and Franklin counties. Such an event is expected to impact ten counties in Washington, with the most significant effects apparent in Grant County, followed by Yakima, Kittitas, Benton, and Franklin.

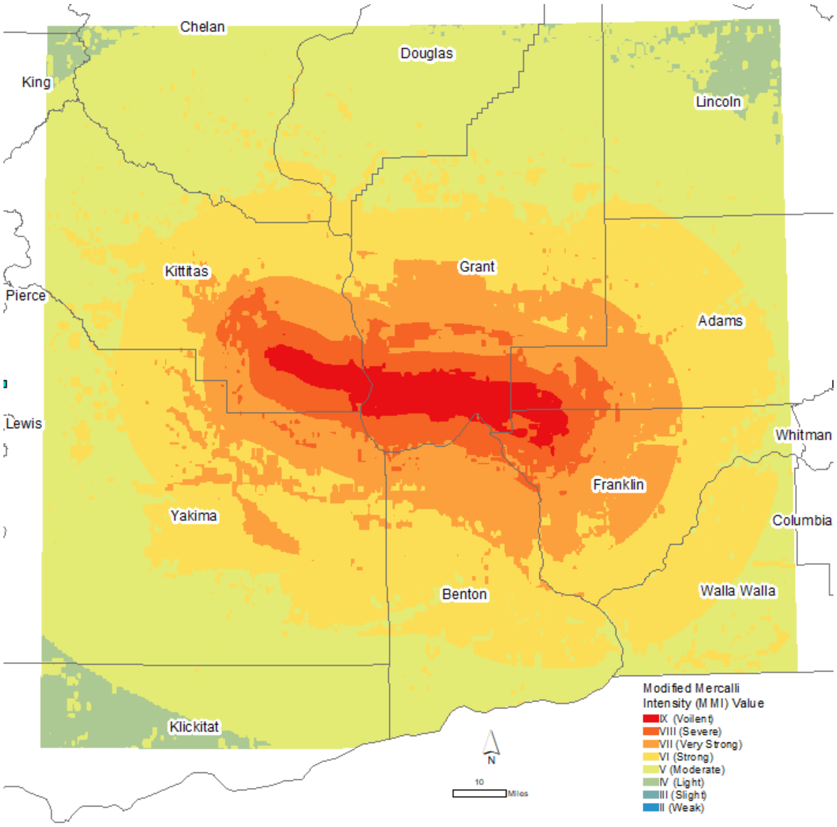


FIGURE AE 14: SADDLE MOUNTAIN FAULT ZONE MAGNITUDE 7.4 EARTHQUAKE SCENARIO SHAKING INTENSITY

Summary of Significant Losses M7.4 Saddle Mountain Scenario Earthquake	
End-to-end length of fault (kilometers)	87
Magnitude (M) of scenario earthquake	7.4
Number of counties impacted	10
Total injuries (*severity 1, 2, 3, 4) at 2:00 PM	278
Total number of buildings extensively damaged	2,520
Total number of buildings completely damaged	832
Income losses in millions	$146
Displaced households	405
People requiring shelter (individuals)	396
Capital stock losses in millions	$590
Debris total in millions of tons	0.27
Truckloads of debris (25 tons per truckload)	10,760
People without power (Day 1)	4,382
People without potable water (Day 1)	1,533

Injuries: The number of people injured in this scenario will likely be highest in Grant County, but dozens of injuries are expected in Kittitas, Yakima, Franklin, and Benton counties. Although many of these injuries will not be life-threatening, some will require hospitalization. Serious injuries are expected in Grant, Kittitas, and Franklin counties; some fatalities are likely in Grant and Kittitas. Serious injuries and fatalities are more likely if a quake occurs during or at the end of the business day.

Damage: Thousands of buildings in Yakima, Grant, Benton, Kittitas, and Franklin counties will be damaged. Much of the damage will be slight to moderate, but extensive damage is also expected, particularly in Grant, Kittitas, Yakima, and Franklin counties. In Grant County, nearly 700 buildings are expected to collapse or to be in danger of collapse (complete damage). Most of the damaged buildings will be residential, but the number of commercial and industrial structures will also be high. Many unreinforced masonry buildings will experience partial or complete collapse.

Economic Losses Due to Damage: Capital stock losses are the direct economic losses associated with damage to buildings, including the cost of structural and non-structural damage, damage to contents, and loss of inventory. Grant and Yakima counties account for the largest portion of the capital stock loss estimate (over $341 million), followed by Benton ($75 million) and Kittitas (over $74 million).

Income losses, including wage losses and loss of rental income due to damaged buildings, are also highest in Grant County (over $45 million) and Yakima County (about $40 million).

Impact on Households and Schools: The number of people without power or water will be highest in Grant and Kittitas counties. These counties also account for many of the displaced households and individuals in need of shelter. The functionality of schools in Grant and Kittitas will also be affected.

Debris Removal: Following an earthquake, debris (brick, wood, concrete, and steel) must be removed and disposed of. Much of this will come from Grant, Yakima, and Kittitas counties (about 211,000 tons).

Estimates vs. Actual Damage: Although this M7.4 earthquake scenario was modeled using the best scientific information available, it represents a simplified version of expected ground motions. The damage resulting from an actual earthquake of similar magnitude is likely to be even more variable and will depend on the specific characteristics and environment of each affected structure.

SeaTac in South-Central Puget Sound Magnitude 7.2 Earthquake

Geologic Description

This scenario is based on a M7.2 deep earthquake centered below SeaTac. Deep earthquakes—also called intraplate or Wadati-Benioff zone earthquakes—are common in western Washington. Over the last 65 years, the largest of these deep earthquakes occurred between Olympia and Seattle in 1949 (M7.0), 1965 (M6.5), and 2001 (M6.8).

Intraplate earthquakes are usually the result of normal faulting within the upper part of a subducting oceanic plate, and typically are not followed by large aftershocks. Beneath western Washington, the depth range of deep earthquakes begins near 30 kilometers (19 miles) and continues downward to about 60 kilometers (37 miles). This depth range is where all the damaging deep earthquakes have been located. In some places, notably central and northern Puget Sound, a few deep earthquake events have been recorded, but their magnitudes tend to be small. The distribution of deep earthquakes allows seismologists to map the surface of the subducting Juan de Fuca plate as it descends into the mantle below western Washington.

Type of Earthquake

Like the M6.8 Nisqually earthquake in 2001, the M7.2 scenario earthquake modeled for the region around SeaTac is a deep earthquake. Deep earthquakes tend to be less damaging than shallow earthquakes of comparable magnitude, primarily because in deeper quakes, the seismic waves lose a majority of its energy by the time they reach the surface. Nevertheless, a deep earthquake of this magnitude will cause serious damage. The shaking from a deep earthquake is also likely to be felt over a much larger area than that from a shallow earthquake.

Aftershocks: Unlike shallow earthquakes, which usually produce numerous aftershocks, a M7.2 deep earthquake like the one in this scenario is not likely to be followed by aftershocks strong enough to be felt.

HAZUS Results for the SeaTac Scenario

HAZUS was used to estimate the losses that could result from a M7.2 deep earthquake beneath SeaTac in King and Pierce counties. Such an event is expected to impact 16 counties in Washington, with the most significant effects apparent in King, Pierce, Snohomish, and Kitsap counties.

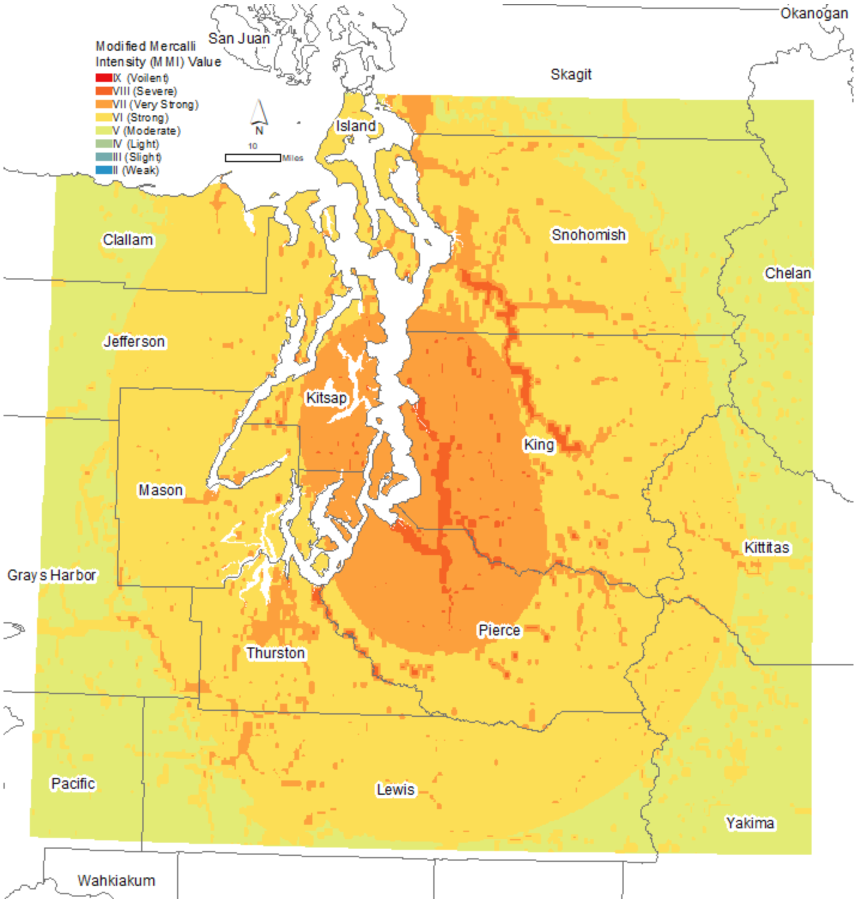


FIGURE AE 15: SEATAC IN SOUTH-CENTRAL PUGET SOUND MAGNITUDE 7.2 EARTHQUAKE SCENARIO SHAKING INTENSITY

Summary of Significant Losses M7.2 SeaTac Scenario Earthquake	
End-to-end length of fault (kilometers)	38
Magnitude (M) of scenario earthquake	7.2
Number of counties impacted	16
Total injuries (*severity 1, 2, 3, 4)	>3,480
Total number of buildings extensively damaged	8,801
Total number of buildings completely damaged	1,123
Income losses in millions	$1,684
Displaced households	6,489
People requiring shelter (individuals)	3,871
Capital stock losses in millions	$8,241
Debris total in millions of tons	2.36
Truckloads of debris (25 tons per truckload)	94,480
People without potable water (Day 1)	132,577

Injuries: The number of people injured in this scenario is likely to be high, particularly if the earthquake occurs during or at the end of the business day. King County is expected to have the highest number of injured people, followed by Pierce, Snohomish, and Kitsap. Many of these injuries may be serious enough to require hospitalization. Numerous fatalities are also likely; the highest numbers are in King and Pierce counties.

Damage: The earthquake will damage thousands of buildings in all the affected counties, but King, Pierce, Snohomish, and Kitsap counties account for the greatest number (over 342,000) and will suffer damage to the highest percentages of their respective building stocks. For many buildings, the damage is expected to be slight to moderate, but a large number will be extensively damaged (over 5,000 in King County alone). Hundreds of buildings are expected to collapse or to be in imminent danger of collapse. Most of these are in King and Pierce counties. A majority of the damaged buildings will be residential, commercial, and industrial, but the total includes buildings of all types and occupancy classes. Many unreinforced masonry and non-ductile concrete buildings are subject to collapse.

Economic Losses Due to Damage: Capital stock losses are the direct economic losses associated with damage to buildings, including the cost of structural and non-structural damage, damage to contents, and loss of inventory. King County accounts for the largest portion of the capital stock loss estimate (over $5 billion), followed by Pierce (over $1 billion) and Snohomish (more than $789 million).

Income losses, including wage losses and loss of rental income due to damaged buildings, are also highest in King County (over $1 billion) and Pierce County (more than $461 million).

Impact on Households and Schools: The number of people without water is highest in King County. This county also accounts for most of the displaced households and individuals in need of shelter. The earthquake is most likely to affect the functionality of schools in King, Pierce, and Kitsap counties.

Debris Removal: Following an earthquake, debris (brick, wood, concrete, and steel) must be removed and disposed of. Much of this will come from King and Pierce counties (about 2,028,000 tons).

Estimates vs. Actual Damage: Although this M7.2 earthquake scenario was modeled using the best scientific information available, it represents a simplified version of expected ground motions. The damage resulting from an actual earthquake of similar magnitude is likely to be even more variable and will depend on the specific characteristics and environment of each affected structure.

Seattle Fault Zone Magnitude 7.2 Earthquake

Geologic Description

The Seattle fault earthquake scenario posits a M7.2 earthquake caused by a 63 kilometer (40 mile)-long rupture on the northernmost strand of the Seattle fault zone from the Kitsap Peninsula to just east of Lake Sammamish. The scenario is based on an earthquake that probably caused a surface rupture on the fault in the Bellevue area thousands of years ago. That event caused about 2 meters (6.5 feet) of surface displacement west of Lake Sammamish near SE 38th Street.

The Seattle fault's location was originally determined using geophysical studies that showed a high amplitude gravity anomaly between uplifted Tertiary volcanic rock to the south and down-dropped Tertiary and Quaternary sediments to the north. This is one of the strongest gravity anomalies in the continental U.S. Later researchers used geologic mapping and high-resolution aeromagnetic and seismic reflection data to locate several subparallel fault strands within an east-trending zone along the gravity anomaly.

A conspicuous platform bordering the shoreline of southern Bainbridge Island, parts of Kitsap County, and Alki Point in West Seattle is the best geological evidence for a large earthquake on the Seattle fault. This intertidal wave-cut platform, cut on Oligocene Blakeley Formation and Miocene Blakely Harbor Formation, was uplifted as much as 8 meters (26 feet) in a single earthquake about 1,100 years ago. Secondary effects of this large earthquake (a tsunami, landslides, and liquefaction) are also documented. Investigation of an 8,000-year history of activity on the Seattle fault found evidence for possibly one additional earthquake on the Seattle fault about 6,900 years ago, suggesting a recurrence interval of thousands of years for large earthquakes.

LIDAR (light detection and ranging) surveys found a fault scarp on southern Bainbridge Island. Subsequent trenching studies across this scarp revealed evidence for up to three surface-rupturing earthquakes in the past 2,500 years. Additional surveys and analysis of existing LIDAR identified potential fault scarps at several other locations within the fault zone. Trenching on scarps at Islandwood on Bainbridge Island and Waterman Point and Point Glover in Kitsap County showed evidence of possibly two surface-rupturing earthquakes about 1,100 years ago. Recent geologic mapping suggests that the Seattle fault zone extends to the Olympic Mountains on the west and the Cascades on the east.

Type of Earthquake

The M7.2 scenario earth-quake modeled for the Seattle fault zone is a shallow or crustal earthquake. Shallow quakes tend to be more damaging than deep quakes of comparable magnitude (such as the deep M6.8 Nisqually earthquake in 2001). This is primarily because in deeper earthquakes, the seismic waves lose a majority of its energy by the time they reach the surface.

Aftershocks: Unlike deep earthquakes, which usually produce few or no aftershocks strong enough to be felt, a M7.2 shallow earthquake like the one in this scenario would likely be followed by many aftershocks, a few of which could be large enough to cause additional damage.

HAZUS Results for the Seattle Fault Scenario

HAZUS was used to estimate the losses that could result from a M7.2 earthquake on the Seattle fault. Such an event is expected to impact fifteen counties in Washington, with the most significant effects apparent in King and Kitsap counties.

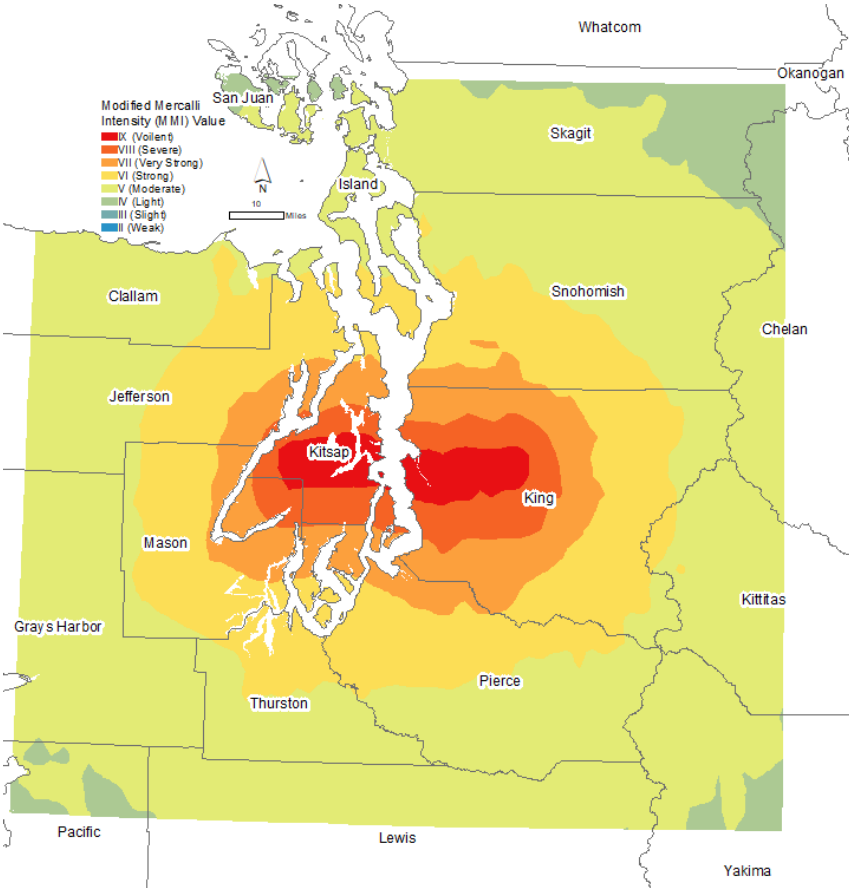


FIGURE AE 16: SEATTLE FAULT ZONE MAGNITUDE 7.2 EARTHQUAKE SCENARIO SHAKING INTENSITY

Summary of Significance Losses M7.2 Seattle Fault Scenario Earthquake	
End-to-end length of fault (kilometers)	68
Magnitude (M) of scenario earthquake	7.2
Number of counties impacted	15
Total injuries (*severity 1, 2, 3, 4) at 2:00 PM	17,677
Total number of buildings extensively damaged	29,094
Total number of buildings completely damaged	9,062
Income losses in millions	$5,133
Displaced households	31,278
People requiring shelter (individuals)	18,193

Capital stock losses in millions	$19,868
Debris total in millions of tons	7.42
Truckloads of debris (25 tons per truckload)	296,720
People without power (Day 1)	265,583
People without potable water (Day 1)	399,991

<u>Injuries</u>: The number of people injured is likely to be high, particularly if the earthquake occurs during or at the end of the business day. King County is expected to suffer the highest number of casualties (as many as 15,615), followed by Kitsap and Pierce counties; many of these injuries will require hospitalization and hundreds may be life-threatening if not treated promptly. Numerous fatalities are also likely, the highest number being in King and Kitsap counties (over 1,000 if the event occurs at 2:00 PM).

<u>Damage</u>: The earthquake will damage thousands of buildings in all the affected counties. King and Kitsap counties account for the largest part of the total (357,789 and 68,094 respectively) and will suffer damage to the highest percentages of their building stocks. In many cases, damage will be slight to moderate, but large numbers of buildings will suffer extensive damage (over 21,000 in King County alone). Thousands of buildings are expected to collapse or to be in imminent danger of collapse (complete damage). Most of these are in King and Kitsap counties. The majority of damaged structures will be residential, commercial, and industrial, but the total includes buildings of all types and occupancy classes. Many unreinforced masonry and non-ductile concrete structures are likely to collapse.

<u>Economic Losses Due to Damage</u>: Capital stock losses are the direct economic losses associated with damage to buildings, including the cost of structural and non-structural damage, damage to contents, and loss of inventory. King and Kitsap counties account for the largest portion of the estimated capital stock loss (nearly $19 billion).

Income losses, including wage losses and loss of rental income due to damaged buildings, are also highest in King County (over $4 billion) and Kitsap County (about $597 million).

<u>Impact on Households and Schools</u>: The number of people without power or water is highest in King and Kitsap counties. In King, 218,464 households will have no power on Day 1; over 333,000 will have no water. King and Kitsap also account for most of the displaced households and individuals in need of shelter. The quake will seriously affect the short- and long-term functionality of schools in these counties.

<u>Debris Removal</u>: Following an earthquake, debris (brick, wood, concrete, and steel) must be removed and disposed of. Much of this will come from King and Kitsap counties (over 7 million tons).

<u>Estimates vs. Actual Damage</u>: Although this M7.2 earthquake scenario was modeled using the best scientific information available, it represents a simplified version of expected ground motions. The

damage resulting from an actual earthquake of similar magnitude is likely to be even more variable and will depend on the specific characteristics and environment of each affected structure.

Latah Fault Zone Magnitude 5.5 Earthquake

Geologic Description

The Spokane scenario is modeled using a M5.5 earthquake on the Latah fault. The Latah fault is inferred to follow a northwest–southeast (almost due north–south) topographic lineament along the modern courses of Hangman Creek and the Spokane River near Spokane. The fault was mapped using topographic lineaments and stratigraphic mismatches across the Hangman Creek watershed. East of the fault, thick deposits of late Miocene Latah Formation with thinner channel fill and invasive flows of Grande Ronde Basalt of the Columbia River Basalt Group (CRBG) are mapped. West of the fault, typical 30 meter (19 foot)-thick flows of Grande Ronde Basalt are intercalated with thin layers of Latah Formation on volcaniclastic sediment. Flows of the Priest Rapids Member of the Wanapum Basalt (CRBG) overlie both units on either side of the fault and do not exhibit appreciable offset, suggesting that most movement on the Latah fault occurred prior to the eruption of the Priest Rapids flows about 14.3 million years ago. No paleoseismology or slip-rate information exists for this fault.

Type of Earthquake

The M5.5 scenario earthquake modeled for the Latah fault is a shallow or crustal earthquake. Shallow earthquakes tend to be much more damaging than deep earthquakes of comparable magnitude (such as the deep M6.8 Nisqually earthquake in 2001). This is primarily because in deeper earthquakes, the seismic waves lose a majority of its energy by the time they reach the surface.

Aftershocks: Unlike deep earthquakes, which usually produce few or no aftershocks strong enough to be felt, a M5.5 shallow earthquake like the one in this scenario will likely be followed by numerous aftershocks, a few of which could be large enough to cause additional damage.

HAZUS Results for the Spokane (Latah Fault) Scenario

HAZUS was used to estimate the losses that could result from a M5.5 scenario earthquake on the Latah fault in Spokane County. Such an event is expected to impact six counties in Washington, with the most significant effects apparent in Spokane County.

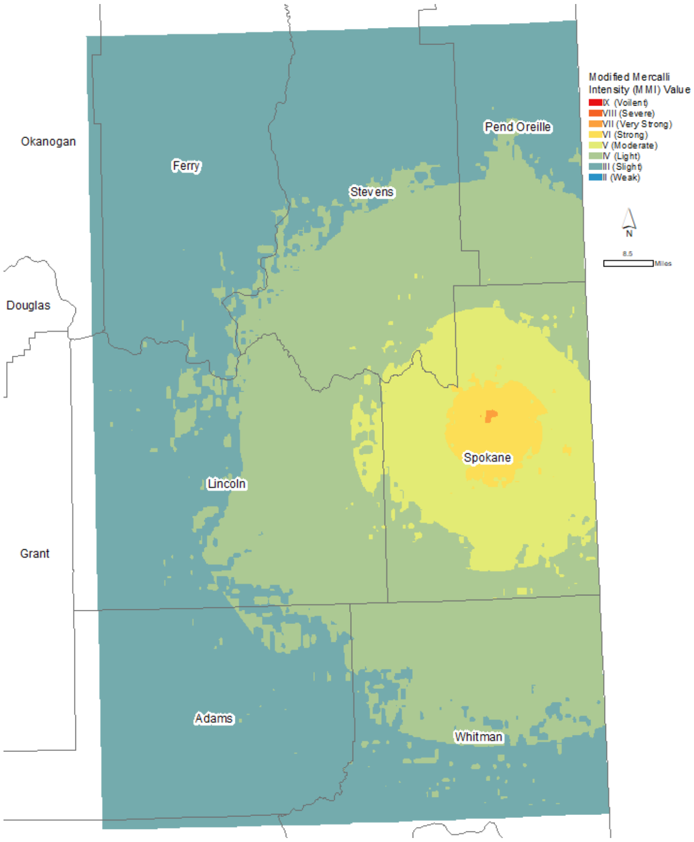


FIGURE AE 17: LATAH FAULT ZONE MAGNITUDE 5.5 EARTHQUAKE SCENARIO SHAKING INTENSITY

Summary of Significant Losses M5.5 Spokane (Latah Fault) Scenario Earthquake	
End-to-end length of fault (kilometers)	5
Magnitude (M) of scenario earthquake	5.5
Number of counties impacted	6
Total injuries (*severity 1, 2, 3, 4) at 2:00 PM	34
Total number of buildings extensively damaged	36
Income losses in millions	$28
Capital stock losses in millions	$361
Debris total in millions of tons	0.04
Truckloads of debris (25 tons per truckload)	1,560

Injuries: Injuries are most likely in Spokane County, where several dozen injuries are expected. Most will not be serious enough to require hospitalization. The number of injuries will be higher if the earthquake occurs during the afternoon, when people are at work and children in school, or at the end of the business day.

Damage: The earthquake is expected to cause slight damage to buildings in some surrounding counties (such as Stevens County). Damage to the contents and non-structural elements of buildings is also anticipated (such as in Pend Oreille County). Buildings in Spokane County will suffer the most damage in this scenario. More than 15,000 buildings in Spokane County are expected to sustain some damage. In most cases, the damage will be slight to moderate, but for several dozen buildings, the damage is likely to be extensive. Most of these damaged buildings will be residential or commercial, although other categories of buildings, such as industrial facilities, will also be affected. Many unreinforced masonry and non-ductile concrete 'tilt up' buildings will likely sustain extensive damage or experience collapse.

Economic Losses Due to Damage: Capital stock losses are the direct economic losses associated with damage to buildings, including the cost of structural and non-structural damage, damage to contents, and loss of inventory. Spokane County accounts for the largest portion of the capital stock loss estimate (nearly $361 million).

Income losses, including wage losses and loss of rental income due to damaged buildings, are also highest in Spokane County (over $28 million).

Impact on Households and Schools: Spokane County accounts for all the estimated displaced households and individuals in need of shelter. Schools in Spokane County may lose some functionality on Day 1 following the earthquake, but the overall impact on schools is not expected to be significant.

Debris Removal: Following an earthquake, debris consisting of brick, wood, concrete, and steel must be removed and disposed of. Most of this will come from Spokane County (about 40,000 tons).

Estimates vs. Actual Damage: Although this M5.5 earthquake scenario was modeled using the best scientific information available, it represents a simplified version of expected ground motions. The damage resulting from an actual earthquake of similar magnitude is likely to be even more variable and will depend on the specific characteristics and environment of each affected structure.

Mount St. Helens Seismic Zone Magnitude 7.0 Earthquake

Geologic Description

The magnitude 7.0 earthquake scenario for the Mount St. Helens seismic zone is based on an approximately 50 kilometer (30-mile)-long rupture within this seismic zone. The zone itself is 100 kilometers (60 miles) long, trending north-to-northwest. It produces earthquakes of moderate magnitude (up to M5.5) that have mostly strike-slip focal mechanisms on north-trending fault planes. This zone of shallow crustal seismicity is not correlated with mapped geological structures, in part because the geology around the zone is shrouded beneath a dense vegetation canopy. The seismic zone appears to stop at about the Cowlitz River—mainly based on a large area of seismic quiescence that developed in the region in the late 1970s—but the zone may extend northward into the Puget Lowland. Regionally, north-trending to northwest-trending seismicity correlates with north-trending and northwest-trending faults mapped in southwestern and south-central Washington.

Type of Earthquake

The M7.0 scenario earthquake modeled for the St. Helens seismic zone is a shallow or crustal earthquake. Shallow earthquakes tend to be much more damaging than deep quakes of comparable magnitude (such as the deep M6.8 Nisqually earthquake in 2001). This is primarily because in deeper earthquakes, the seismic waves lose a majority of its energy by the time they reach the surface.

Aftershocks: Unlike deep earthquakes, which usually produce few or no aftershocks strong enough to be felt, a M7.0 shallow earthquake like the one in this scenario would likely be followed by many aftershocks, a few of which could be large enough to cause additional damage.

HAZUS Results for the Mount St. Helens Scenario

HAZUS was used to estimate the losses that could result from a M7.0 scenario earthquake on the St. Helens seismic zone, which crosses Lewis, Cowlitz, and Skamania counties. Such an event is expected to impact 14 counties in Washington, with the most significant effects apparent in Lewis County, followed by Cowlitz, Clark, and Thurston.

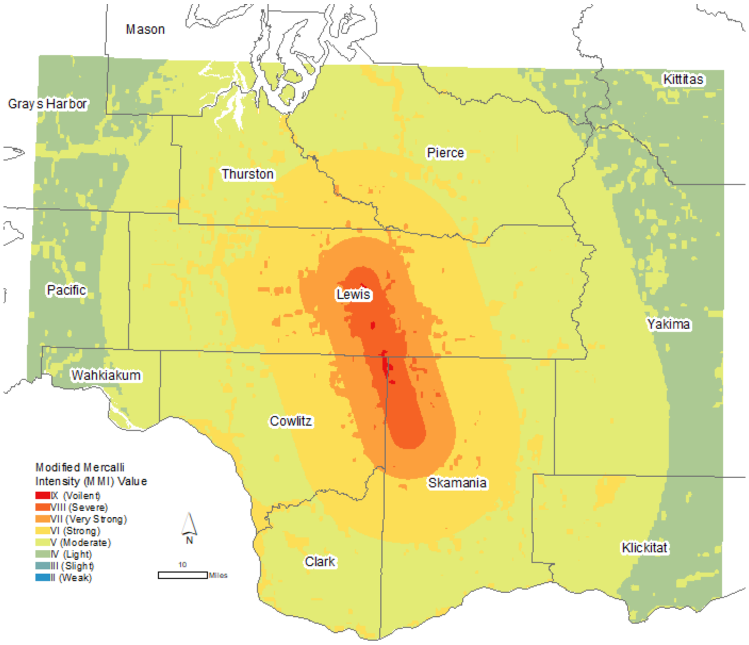


FIGURE AE 18: MOUNT ST. HELENS SEISMIC ZONE MAGNITUDE 7.0 EARTHQUAKE SCENARIO SHAKING INTENSITY

Summary of Significant Losses M7.0 St. Helens Scenario Earthquake	
End-to-end length of fault (kilometers)	51
Magnitude (M) of scenario earthquake	7.0
Number of counties impacted	14
Total injuries (*severity 1, 2, 3, 4) at 2:00 PM	25
Total number of buildings extensively damaged	119
Income losses in millions	$19
Displaced households	10
Capital stock losses in millions	$162
Debris total in millions of tons	0.03
Truckloads of debris (25 tons per truckload)	1,120

<u>Injuries</u>: In general, people are more likely to be injured if the earthquake occurs during or at the end of the business day. The overall number of people injured in this scenario is low. The number will be highest in Lewis County; some injuries are also expected in Clark, Cowlitz, and Thurston counties. Although most of these injuries will not be life- threatening, a few will require hospitalization.

<u>Damage</u>: The highest number of damaged buildings will be in Lewis County (over 4,000), followed by Thurston, Clark, and Cowlitz counties (about 1,800 buildings each). Most of this damage will be slight to moderate, but extensive damage is also expected, particularly in Lewis County, which accounts for 108 of the buildings in this category. While most of the damaged buildings will be residential, buildings of all types and occupancy classes (including commercial and industrial structures) are represented in the damage totals. Unreinforced masonry buildings are especially

vulnerable.

<u>Economic Losses Due to Damage</u>: Capital stock losses are the direct economic losses associated with damage to buildings, including the cost of structural and non-structural damage, damage to contents, and loss of inventory. Lewis County accounts for the largest portion of the capital stock loss estimate (over $39.6 million), but for two other counties, the loss estimate is nearly as high: Clark (over $36.5 million) and Cowlitz (about $28.5 million).

Income losses, including wage losses and loss of rental income due to damaged buildings, are also highest in Lewis County (nearly $8.5 million) and Cowlitz County (over $4 million).

<u>Impact on Households and Schools</u>: In this scenario, Lewis, Cowlitz, and Clark counties account for all the displaced households and individuals in need of shelter. Overall, the functionality of schools is not expected to be significantly affected by the earthquake, except for schools in Lewis County.

<u>Debris Removal</u>: Following an earthquake, debris consisting of brick, wood, concrete, and steel will have to be removed and disposed of. Much of this will come from Lewis and Cowlitz counties (about 18,000 tons).

<u>Estimates vs. Actual Damage</u>: Although this M7.0 earthquake scenario was modeled using the best scientific information available, it represents a simplified version of expected ground motions. The damage resulting from an actual earthquake of similar magnitude is likely to be even more variable and will depend on the specific characteristics and environment of each affected structure.

Southern Whidbey Island Fault Zone Magnitude 7.4 Earthquake

Geologic Description

The southern Whidbey Island fault (SWIF) stretches from the vicinity of Victoria, B.C., across Puget Sound as far as the Cascade Range. This scenario was modeled on the part of the SWIF from Woodinville to just west of Whidbey Island. The SWIF has been assessed by the USGS as capable of generating the largest crustal earthquake in Puget Sound.

The SWIF was originally envisioned as a single, steeply dipping, north-side-down fault reaching from Port Townsend to Woodinville. Over the past 15 years, geological and geophysical studies have extended the SWIF beyond this and reinterpreted the SWIF as a broad, north-side-up fault zone (6–11 kilometers; 4–7 miles wide) dipping steeply to the northeast. It has now been traced to the eastern Strait of Juan de Fuca. Seismic tomography has tracked the fault along the northwestern margin of the Port Townsend basin, where it is thought to merge with the Darrington–Devils Mountain fault zone near Victoria, B.C.

Geologic mapping has extended the SWIF from the eastern edge of Puget Sound southeastward to the vicinity of North Bend. LIDAR and aeromagnetic data confirm that the SWIF projects onto the mainland near Everett and continues southeast towards Woodinville. A series of faults and folds in the Snoqualmie area have recently been mapped that likely correlate with the SWIF. These faults merge with mapped faults on Rattlesnake Mountain near North Bend and continue southeast into the Cascade Mountains.

Current researchers used aeromagnetic data to correlate faults in the Yakima fold and thrust belt with faults west of the Cascades. In their model, geophysical lineaments and mapped structures associated with Umtanum Ridge pass through the Cascades and merge with geophysical lineaments and mapped structures on and near Rattlesnake Mountain in western Washington. If this model is correct, the SWIF now extends about 385 kilometers (240 miles), from Victoria, B.C., to Hanford, Washington.

Paleoseismology: Radiocarbon and stratigraphic data collected from sites on either side of the SWIF on Whidbey Island showed that the sea-level histories of the two sites were not comparable. Instead, the relative sea-level curves diverged 3,200 to 2,800 years ago, suggesting 1 to 2 meters of uplift along the north side of the fault. This suggests the fault has been active in the past. Based on these calculations, researchers concluded that the SWIF can produce a magnitude 6.5 to 7.0 earthquake.

Excavations across several scarps near Woodinville revealed evidence of at least four earthquakes since deglaciation about 16,000 years ago, the most recent being less than 2,700 years ago. Considering this and other research, the potential size of an earthquake on the SWIF was revised to M7.5.

Type of Earthquake

The magnitude 7.4 earthquake modeled for the southern Whidbey Island fault zone is a shallow or crustal earthquake. Shallow quakes tend to be much more damaging than deep quakes of comparable magnitude (such as the M6.8 Nisqually earthquake in 2001). This is primarily because in deeper earthquakes, the seismic waves lose a majority of its energy by the time they reach the surface.

Aftershocks: Unlike deep earthquakes, which usually produce few or no aftershocks strong enough to be felt, a M7.4 shallow earthquake would likely be followed by many aftershocks, a few of which could be large enough to cause additional damage.

HAZUS Results for the SWIF Scenario

HAZUS was used to estimate the losses that could result from a M7.4 deep earthquake on the southern Whidbey Island fault zone (SWIF). Such an event is expected to impact eighteen counties in Washington.

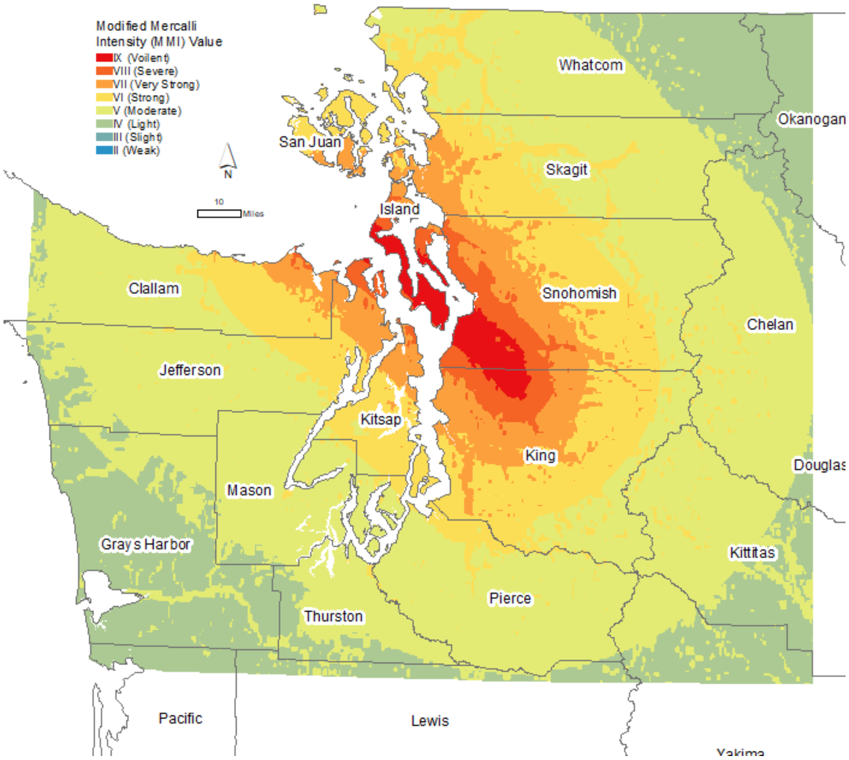


FIGURE AE 19: SOUTHERN WHIDBEY ISLAND FAULT ZONE MAGNITUDE 7.4 EARTHQUAKE SCENARIO SHAKING INTENSITY

Summary of Significant Losses M7.4 Southern Whidbey Island Scenario Earthquake	
End-to-end length of fault (kilometers)	92
Magnitude (M) of scenario earthquake	7.4
Number of counties impacted	18
Total injuries (*severity 1, 2, 3, 4) at 2:00 PM	7,793
Total number of buildings extensively damaged	17,502
Total number of buildings completely damaged	6,258
Income losses in millions	$2,224
Displaced households	13,948
People requiring shelter (individuals)	8,106
Capital stock losses in millions	$10,315
Debris total in millions of tons	3.57
Truckloads of debris (25 tons per truckload)	142,960
People without power (Day 1)	115,230
People without potable water (Day 1)	188,457

Injuries: The number of people injured is likely to be high, particularly if the earthquake occurs during or at the end of the business day. Snohomish County is projected to have the highest number of injured (2,000–6,000), followed by King and Island. Many are likely to require hospitalization; hundreds of injuries may be life-threatening if not treated promptly. Hundreds of fatalities are also likely, the majority in Snohomish, King, and Island counties.

Damage: This earthquake is projected to damage buildings in all the affected counties. Snohomish, King, and Island counties account for the greatest number (over 288,000) and may suffer damage to the highest percentages of their building stocks. In many cases, damage will be slight to moderate, but many buildings are projected to suffer extensive damage (over 10,000 in Snohomish County alone). Thousands of buildings may collapse or be in imminent danger of collapse, especially in Island, Snohomish, and King counties. Many un- reinforced masonry and non-ductile concrete 'tilt up' buildings will experience partial to total collapse. Most damaged structures will be residential, commercial, and industrial, but the total includes buildings of all types and occupancy classes.

Economic Losses Due to Damage: Capital stock losses are the direct economic losses associated with damage to buildings, including the cost of structural and non-structural damage, damage to contents, and loss of inventory. Snohomish and King counties account for the largest portion of the capital stock loss estimate (over $9 billion).

Income losses, including wage losses and loss of rental income due to damaged buildings, are also highest in Snohomish County (over $1 billion) and King County (more than $763 million).

Impact on Households and Schools: The number of people without power or water is projected to be highest in King, Snohomish, and Island counties; these counties account for most of the displaced households and individuals in need of shelter. The earthquake is most likely to affect the functionality of schools in Snohomish and Island counties.

Debris Removal: Following an earthquake, debris (brick, wood, concrete, and steel) must be removed and disposed of. Much of this will come from King and Pierce counties (over 3 million tons).

Estimates vs. Actual Damage: Although the M7.4 earthquake scenario for the southern Whidbey Island fault zone was modeled using the best scientific information available, it represents a simplified version of expected ground motions. The damage resulting from an actual earthquake of similar magnitude is likely to be even more variable and will depend on the specific characteristics and environment of each affected structure.

Tacoma Fault Zone Magnitude 7.1 Earthquake

Geologic Description

The M7.1 earthquake scenario for the Tacoma fault zone is based on a 56 kilometer (35 mile)-long rupture of the fault zone between Kent and Union. The source of this event would probably include surface rupture along a large portion of the fault zone, and the region would experience very strong ground motions.

Evidence for the Tacoma fault zone consists of several geophysical lineaments along the southern and western flanks of the Seattle uplift, with as much as 6 to 7 kilometers (~4 miles) of structural relief estimated on top of Eocene basalts. The fault may merge with the White River fault zone at Enumclaw and continue eastward through the Cascade Range, eventually merging with structures in the Yakima fold and thrust belt.

Geologic evidence for past activity of the Tacoma fault includes raised tidal-flat deposits and shorelines along Hood Canal, Case Inlet, and Carr Inlet. Radiocarbon ages of peat and delicate plant fossils suggest that freshwater peat began forming over former tide-flat muds between 900 and 1,300 years ago, indicating uplift of the tidal flats in that time period. LIDAR surveys along the Tacoma fault zone revealed faults scarps near Belfair and Allyn. These scarps, as high as 4 meters (13 feet) in places, suggest that the Tacoma fault ruptured the ground surface in the recent past. Trenches across the Catfish Lake scarp showed evidence of a late Holocene earthquake that folded glacial deposits and young soils; this is associated with locally uplifted shorelines along Case Inlet and Hood Canal, which were raised as much as 4 meters (13 feet) in the late Holocene between 1,240 and 850 years ago. Additional trenches across two other scarps, both situated in the upthrown block of the Tacoma fault zone, show evidence of right-lateral oblique and normal faulting between 600 and 1,300 years ago. These ages are consistent with a large regional earthquake on the Tacoma fault zone between 1,240 and 850 years ago.

Type of Earthquake

The magnitude 7.1 scenario earthquake modeled for the Tacoma fault zone is a shallow or crustal earthquake. Shallow earthquakes tend to be more damaging than deep quakes of comparable magnitude (such as the deep M6.8 Nisqually earthquake in 2001). This is primarily because in deeper earthquakes, the seismic waves lose a majority of its energy by the time they reach the surface.

Aftershocks: Unlike deep earthquakes, which usually produce few or no aftershocks strong enough to be felt, a M7.1 shallow earthquake like the one in this scenario would likely be followed by many aftershocks, a few of which could be large enough to cause additional damage.

HAZUS Results for the Tacoma Fault Scenario

HAZUS was used to estimate the losses that could result from a M7.1 earthquake on the Tacoma fault. Such an event is expected to impact sixteen counties in Washington, with the most significant effects apparent in King, Pierce, and Kitsap counties.

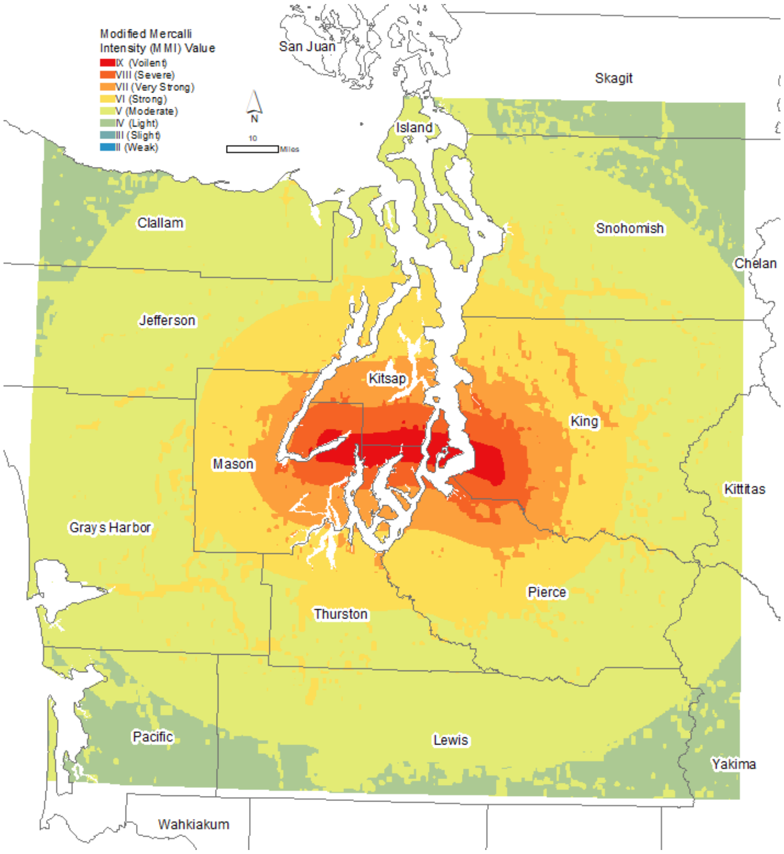


FIGURE AE 20: TACOMA FAULT ZONE MAGNITUDE 7.1 EARTHQUAKE SCENARIO SHAKING INTENSITY

Summary of Significant Losses M7.1 Tacoma Fault Scenario Earthquake	
End-to-end length of fault (kilometers)	68
Magnitude (M) of scenario earthquake	7.1
Number of counties impacted	16
Total injuries (*severity 1, 2, 3, 4) at 2:00 PM	6,070
Total number of buildings extensively damaged	15,410
Total number of buildings completely damaged	4,457
Income losses in millions	$1,847
Displaced households	11,576
People requiring shelter (individuals)	7,146
Capital stock losses in millions	$8,654
Debris total in millions of tons	2.95
Truckloads of debris (25 tons per truckload)	117,960
People without power (Day 1)	87,675
People without potable water (Day 1)	193,544

Injuries: The number of people injured is likely to be high, particularly if the earthquake occurs during or at the end of the business day. King County is expected to suffer the highest number of injuries (as many as 5,151), followed by Pierce and Kitsap counties; many of these injuries will be serious enough to require hospitalization and some may be life-threatening if not treated promptly. Numerous fatalities are also likely, the highest number being in King and Pierce counties (over 300 at 2:00 PM).

Damage: The earthquake will damage thousands of buildings in all the affected counties. The highest numbers are in King, Kitsap, Mason, Pierce and Thurston counties. King and Pierce counties account for the largest part of the total (184,893 and 70,319 respectively). In many cases, damage will be slight to moderate, but the number of buildings likely to suffer extensive damage is very high (nearly 10,000 in King County alone). Thousands of buildings are expected to collapse or to be in imminent danger of collapse. Most of these are in King County, but Pierce, Kitsap and Mason counties account for more than 1,500. The majority of damaged structures will be residential, commercial, or industrial, but the totals include buildings of all types and occupancy classes. Unreinforced masonry and non-ductile concrete 'tilt up' buildings are likely to experience partial to full collapse.

Economic Losses Due to Damage: Capital stock losses are the direct economic losses associated with damage to buildings, including the cost of structural and non-structural damage, damage to contents and loss of inventory. King and Pierce counties account for the largest portion of the capital stock loss estimate (well over $7 billion).

Income losses, including wage losses and loss of rental income due to damaged buildings, are also highest in King County (over $1.4 billion) and Pierce County (about $276 million).

Impact on Households and Schools: The number of people without power or water is highest in King, Pierce, and Kitsap counties. These three counties also account for most of the displaced households and individuals in need of shelter. The earthquake will most affect the functionality of schools in Mason, King, Kitsap and Pierce counties.

Debris Removal: Following an earthquake, debris (brick, wood, concrete, and steel) must be removed and disposed. Much of this will come from King and Pierce counties (over 2.6 million tons).

Estimates vs. Actual Damage: Although this M7.1 earthquake scenario was modeled using the best scientific information available, it represents a simplified version of expected ground motions. The damage resulting from an actual earthquake of similar magnitude is likely to be even more variable and will depend on the specific characteristics and environment of each affected structure.

Flood Risk Summary

Washington State Risk Index for Flood (WaSRI-F)

🟧

LIKELIHOOD

🟥 HIGH

The probability for 10 or more flooding events in a year is estimated as 81% based on data since 2000. Climate Change will increase the frequency of Winter flooding for most rivers. Summer discharges will reduce for most Cascade drainages as they become increasingly rain dominant, losing their spring/summer snow fed flows.

HAZARD AREA

🟧

While most communities in Washington are exposed to flood hazards, the total area designated as at risk from 1% or 0.2% annual chance of flooding is less than 10% of the total area of the state. However, based on experience, flooding events are likely to inundate much larger areas beyond the designated floodplain boundaries.

POPULATION

🟥

About 11% of the State population resides in areas with 1% or 0.2% annual chance of flooding. However, approximately 45% of the State population resides in census tracts with designated floodplains.

VULNERABLE POPULATION

🟧

Less than 5% of the State population resides in areas ranked medium or higher on social vulnerability and are exposed to 1% or 0.2% annual chance of flooding. In contrast, it is estimated that three times this number of population is location in census tracts with designated floodplains.

BUILT ENVIRONMENT

🟨

About 11% of the total building stock in the state is located in areas with 1% or 0.2% annual chance of flooding.

CRITICAL INFRASTRUCTURE

⬜

About 5% of the critical infrastructure facilities are in areas with 1% or 0.2% annual chance of flooding.

STATE FACILITIES

⬜

Less than 5% of State Owned facilities are in areas with 1% or 0.2% annual chance of flooding.
Less than 5% of the State Leased facilities are in areas with 1% or 0.2% annual chance of flooding.

FIRST RESPONDERS

⬜

6% of the Fire Stations are in areas with 1% or 0.2% annual chance of flooding.
8% of the Law Enforcement facilities are in areas with 1% or 0.2% annual chance of flooding.
6% of the EMS facilities are in areas with 1% or 0.2% annual chance of flooding.

ECONOMIC CONSEQUENCES

🟥 HIGH

Counties ranked medium or higher on WaSRI-F account for 83% of real State GDP.

ENVIRONMENTAL IMPACTS

⬜ LOW

Flooding serves an important function of floodplain enrichment. Most of the ecological species in the floodplain are well-adapted to frequent flooding. Climate Change will bring increases in Winter discharge with more sediment transported. Lower Spring/Summer flows will stress forest ecology, salmon runs and lead to prairie expansion.

Hazard Description

Flooding is the partial or complete inundation of normally dry land. Flooding often results from intense rain events and periods of continuous rainfall; this can also combine with snowmelt. Flooding is one of the most common natural hazards in Washington state, and it plays a critical role in the provisioning of a host of ecosystem services.

Flooding affects every county. Since 1953, there have been 28 Presidential Disaster Declarations for flooding in Washington. These floods severely impact local businesses and economies as work stops and damage is addressed. The potential highway closures have devastating effects on the movement of essential goods, trade, and people across the state. For example, the US Army Corps of Engineers (USACE) Skagit River Flood Damage Reduction Feasibility Study determined a 100-year flood event could devastate Skagit County's economy with damages exceeding $1 billion. In 2012, alone, flooding cost over $40 million in damages. Road, railroad, and pipeline transportation jeopardized by a severe flood event would force business and manufacturing shutdowns and close major commuter routes.

Washington is among the most flood-prone states west of the Mississippi River. In Washington, the costs of flood damages exceed the cost of all other natural hazards. Some of the notable Washington State flood facts include:

- In 1997, Washington had the highest number of declared flood disasters in the country.
- Washington ranks high in flood insurance policies – 36,700 policies providing $ 9.4 billion in insurance coverage (FEMA Community Information System, Accessed 4/4/18).
- More than 30 percent of flood insurance policies are outside the mapped Special Flood Hazard Area.
- In Western Washington, the actual occurrence of a flood on any river system that drains to the Puget Sound is roughly every 4.5 years.

Flooding in Washington state typically occurs on a seasonal basis from:

- Rainfall accompanying atmospheric rivers.
- Rainfall on frozen ground in early fall or winter
- Rainfall combined with snow melt causing winter and early spring flooding
- Late spring flooding from snow pack melt, particularly in Eastern Washington (this will likely diminish with climate change)
- Thunderstorms causing flash floods, mainly in Eastern Washington, with some winter storms causing flash flooding in Western Washington.
- Winter storms, accompanying storm surges and high tides.

Several types of floods occur in Washington. In most parts of Western Washington, floods generally occur in late fall and winter from prolonged rainstorms. These floods may be augmented by water from snowmelt if rain falls on snow. The rain-on-snow floods are usually of short duration. In basins at higher elevations, floods may occur in the spring from rapid snowmelt. These floods are usually less severe but continue for a longer duration than winter floods.

In Eastern Washington, floods generally occur in the foothills of the Cascade Range and in the highlands of Northeastern Washington during spring snowmelt. In some areas of Eastern Washington, flooding may occur during the winter when rain or unseasonably warm weather melts accumulations of snow. Flooding may also occur in small basins in response to summer thunderstorms.

The following are the general types of flooding commonly recognized by the practitioners:

- Overbank flooding (also riverine or fluvial flooding): Rivers and streams overrun their banks when swollen with rainfall, snowmelt, or a combination of both. Flood severity is the result of depth, duration, velocity, debris loads, and contamination from hazardous materials. Overbank flooding is most common from November to February but can occur any time of the year. Climate change impacts, wildfires with reductions in permeability and sediment mobilization and landslides blocking rivers discharge can all increase this type of flooding.
- Coastal storm surge flooding: Storm surges, low barometric pressure, and tides can combine to create coastal flooding. Peak surges that coincide with high tides can cause the worst damage. Storm surge severity depends on depth, debris, and wave effects such as continued pounding. Coastal flooding is worsening with rising sea levels and changing weather patterns.
- Storm water drainage flooding (also urban, surface or pluvial flooding): Storm water from sewer pipes, drains, and related infrastructure, not typically connected to a specific drainage, can inundate urban neighborhoods, flooding homes, streets and buildings. Heavy and persistent rainfall can overwhelm urban systems and cause localized flooding. Treatment plants may not be able to handle the volume and need to discharge untreated sewage into local water bodies. Climate change is increasing the frequency of more intense storms.
- Infrastructure failure induced flooding: Levees, dams, pipelines, and reservoirs can fail and cause flooding. Infrastructure managed and regulated by federal and state agencies tends to be well designed and maintained. Failures in smaller systems maintained by local governments, special districts (drainage, irrigation), and private ownership are more common. Levees can be overtopped by flood waters or fail due to foundation problems, seepage, animal burrows, and other issues.
- Flash Floods: These are characterized by a rapid rise in water level, often high velocity, and large amounts of debris. They are capable of tearing out trees, undermining buildings and bridges, and scouring new channels with little or no warning. Major factors in flash flooding are the intensity and duration of rainfall and the steepness of watershed and stream gradients and little warning. The amount of watershed vegetation, the natural and artificial flood storage areas, and the configuration of the stream bed and floodplain are also important. Flash floods may result from the failure of a dam, rapid snowmelt, loss of vegetation due to wildfire, or the sudden breakup of an ice jam. Any of these can cause the release of a large volume of water in a short period of time. Flash flooding in urban areas is an increasingly serious problem due to the removal of vegetation, paving and the replacement of ground cover with impermeable surfaces that increase runoff, and the

construction of drainage systems that increase the speed of runoff. As our changing climate brings more intense rainfall and stresses to hillside vegetation resulting from hotter, dryer summers, flash flooding risks are expected to increase.

- Ice Jam Floods: Flooding caused by ice jams is similar to flash flooding. Ice jam formation causes a rapid rise of water at the jam and extends upstream. Failure or release of the jam causes sudden flooding downstream. The formation of ice jams depends on the weather and physical conditions in river channels. Ice jams are most likely to occur where the channel slope naturally decreases, where culverts freeze solid, at headwaters of reservoirs, at natural channel constrictions such as bends and bridges, and along shallows where channels may freeze solid. Ice jam floods can occur during fall and freeze-up from the formation of frazil ice; during midwinter periods when stream channels freeze solid to form anchor ice; and during spring break-up when rising water levels from snowmelt or rainfall break the existing ice cover into large floating masses that lodge at bridges and other constrictions. Damage from ice jam flooding is usually worse than damage caused by open water flooding. Flood elevations are usually higher than predicted for free-flow conditions, and water levels may change rapidly. Additional physical damage is caused by the force of ice striking buildings and other structures. Global warming is causing fewer extreme cold weather-related events for many communities thereby reducing this risk.
- Flooding from other sources: Earthquakes, volcanoes, wildland fires, and landslides can also generate flooding. Earthquakes can cause the ground to shake, lift, drop and split. Such ground motion can break major pipelines, dams and reservoirs. A Cascadia Subduction Zone earthquake can generate tsunamis and cause coastal flooding. Volcanoes can generate lahars that block rivers and streams. Wildland fires can reduce the ground's capacity to absorb water. Landslides can block rivers and streams and set off seiches.

Flood Hazard Location, Extent, and Magnitude

A floodplain is identified as the land along a river that is identified as being susceptible to flooding. The federal standard for floodplain management under the National Flood Insurance Program (NFIP) is the "base floodplain" (also known as the 100-year floodplain, 1 percent annual chance floodplain, and Special Flood Hazard Area [SFHA]). This area is determined using historical data indicating that in any given year there is a 1 percent chance of the base flood occurring. A base flood is one that covers or exceeds the determined floodplain.

Floods vary greatly in frequency and magnitude. Small flood events occur much more frequently than large, devastating events. Statistical analyses of past flood events can be used to establish the likely magnitude and recurrence intervals (period between similar events) of future events. The most commonly reported flood magnitude measure is the "base flood." In any given year, there is a 1%, or 1 in 100, probability that water levels will exceed this magnitude. Base floods can occur in any year, even successive ones. The term "base flood or base floodplain" was derived from a policy decision made when the NFIP was institutionalized and it was decided that a 1 percent flood will be used as the basis for regulation. It was arbitrary. Actually, more annual damage typically results from 10 percent or 25 percent floods and accordingly many communities have higher regulatory standards for these more frequent events.

The floodplain is the area that normally carries flood waters adjacent to the channel. In practical terms, a floodplain is the area inundated by floodwaters; this area changes based on the magnitude of the flood event. Where the surface of the land is relatively undisturbed by human activities, flood prone areas can be recognized by a well-defined natural flat "floodplain", natural levees along stream banks, alluvial fans, abandoned channel meanders, or soil types that are associated with floodplains. In altered or urbanized areas, these features will be less distinct; they may be obscured or removed by development. Further, where structures have been placed in the floodplain, the natural flooding processes may have been so altered that these features no longer accurately define the floodplain. In regulatory terms, a floodplain is an area where specific regulations and programs (such as the NFIP) apply.

The floodway, a subdivision of the floodplain, is of special regulatory interest. More stringent regulations are imposed in the floodway because changes here can have a greater impact on the overall flood regime than those in the remainder of the floodplain (the 'flood fringe'). A floodway is the area needed to convey floodwaters during a 1 percent discharge event. By regulation it is usually with the FEMA defined water course.

Application of these terms and concepts to flash and ice/debris jam break floods can be difficult. The term "inundation zone" may be used in place of floodplain and should be considered analogous. Like floodplains, inundation zones may be determined by projecting the anticipated volume of water (e.g., runoff from the 'base' storm, the storage capacity of the dam that may fail, or excess runoff not conducted by a storm water system). Historical inundation zones may be observed through field study of terrain features and vegetation; although they may be associated with recognizable terrain features such as canyons or gulches, areas subject to these floods are often less obvious than those located on a typical riverine floodplain.

Western Washington counties in the Puget Sound and Pacific Coast have the greatest risk to flood, with significant waterways that flood regularly and high levels of development, including development in flood prone areas.

Many rivers in Western Washington typically flood every two to five years; damaging flood events occur less frequently. Rivers that often produce damaging floods, include rivers flowing off the west slopes of the Cascade Mountains (Cowlitz, Green, Cedar, Snoqualmie, Skykomish, Snohomish, Stillaguamish, Skagit, Nisqually, Puyallup, Lewis, and Nooksack); out of the Olympic Mountains (Satsop, Elwha, Dungeness, and Skokomish); and out of the hills of southwest Washington (Chehalis, Naselle, and Willapa). Long periods of rainfall and mild temperatures are normally the cause of flooding on these streams. It is important to note that climate change is bring warmer winter temperatures with more frequent higher intensity rainfall events.

Several rivers in Eastern Washington also flood every two to five years, including the Spokane, Okanogan, Methow, Yakima, Walla Walla, and Klickitat; again, damaging events occur less frequently. Flooding on rivers east of the Cascades usually results from periods of heavy rainfall on wet or frozen ground, mild temperatures, or from the spring runoff of mountain snow pack.

Eastern Washington is prone to flash flooding. Thunderstorms, combined with steep ravines, alluvial fans, dry or frozen ground, and lightly vegetated ground that does not absorb water can result in flash flooding.

All Pacific coastal counties, Puget Sound and Strait of Juan de Fuca coastal counties, and counties at the mouth of the Columbia River, are susceptible to on-shore wind and barometric tidal flooding. These are often called “King” tides and offer an illustration of expected climate change impacts.

Occasionally, communities experience surface water flooding due to high groundwater tables. This occurred dramatically during the 1996-97 winter storms. In many communities, residents outside of identified or mapped flood plains had several inches of water in basements due to groundwater seepage. These floods contaminated domestic water supplies, fouled septic systems, and inundated electrical and heating systems. Fire-fighting access was restricted, leaving homes vulnerable to fire. Lake levels were the highest in recent history, and virtually every county had areas of ponding not previously seen.

Urban areas across the state have also experienced urban or surface flooding when a developed community’s storm water drainage system is overwhelmed by excessive rainfall and runoff from impervious surfaces such as roads and parking lots. While normally not life-threatening, such urban flooding can be very disruptive for residents. These events may increase as urban areas develop rapidly without commensurate improvements in urban drainage infrastructure.

Riverine floodplains make up about 4.5 percent of the state's total land area based on the 1.0-percent annual chance flood modeled for this plan. Only about 25 to 35 percent of homes in floodplains have insurance for flood losses. Uninsured homeowners face greater financial liability than they realize. For example, the monthly payment for a $50,000 federal disaster assistance loan at 4 percent interest, would be around $240 a month ($2,880 a year) for 30 years. Compare that to a $100,000 flood insurance premium, which is about $400 a year ($33 a month). During a typical 30-year mortgage period, a home in a mapped floodplain has 26 percent chance of damage by a 100-year flood event. The same structure only has about a 1 percent chance of damage by fire.

A recent risk assessment study by Department of Ecology offers flood risk ranks for each of the 71 watersheds (ECY 2016). The risk assessment factors included, populations density (weighted 60%), NFIP policies & claims (30%), and floodplain area (10%). All three weighted factors were sorted in ascending order and assigned a value from one to seventy-one with the highest risk watersheds assigned the lowest values. The three rankings were summed equally and again assigned a rank value with the highest risk watersheds assigned the lowest values. The resulting assessment assigned a value to all seventy-one watersheds.

Top 20 at risk Watershed in Washington State				
HUC8 Name	Final Risk Rank	Floodplain Area Rank	Population Density Rank	Policies & Claims Rank
Lower Skagit	1	2	11	1
Puget Sound	2	17	3	3
Strait of Georgia	3	7	9	9
Upper Chehalis	4	3	22	2
Snohomish	5	18	4	15
Puyallup	6	23	8	6
Lower Yakima	7	4	14	17
Snoqualmie	8	21	15	4
Grays Harbor	9	13	23	7
Duwamish	10	42	5	5
Lake Washington	11	45	1	8
Nooksack	12	11	18	19
Stillaguamish	13	20	21	11
Nisqually	14	22	12	25
Lower Willamette	15	28	7	27
Lower Chehalis	16	6	29	21
Lower Cowlitz	17	19	28	13
Lower Columbia-Clatskanie	18	29	26	16
Upper Yakima	19	15	36	18
Snohomish	20	33	33	10

State Floodplain Management Program

The Washington State Department of Ecology (Ecology) Floodplain Management Program plays an important role in state mitigation with respect to flooding events as the lead agency for flood risk reduction, designated as such in Washington law. Program staff assists communities in administering their local floodplain management programs, make substantial damage determinations after a flood and ensure that communities are compliant with their local ordinances. In addition, they work to assist non-participating communities that wish to enter the National Flood Insurance Program (NFIP) and provide technical assistance to participating communities interested in enrolling in the Community Rating System (CRS). Floodplain Management staff provides training to local government and emergency management officials on floodplain management and mitigation. Ecology also developed the Comprehensive Planning for Floodplain Management Guidebook, which provides additional planning guidance for local jurisdictions to meet FMA planning requirements with respect to NFIP, floodplain management and mitigation planning.

In addition to the above, Ecology supports ongoing updates to existing FEMA floodplain mapping and risk reduction programs. Ecology's Floodplain Management Program has partnered with FEMA under two FEMA programs - Map Modernization and Risk MAP - in support of effective implementation of floodplain regulations and flood hazard reduction.

General Regulatory Provisions for Floodplain Management in Washington

- RCW 36.70A.170 and .172 - GMA Critical Areas Designation - Jurisdictions planning under the Growth Management Act are required to designate and protect frequently flooded areas as part of the requirements for critical areas.
- Ch. 86.12 RCW - Flood Control by Counties (River Improvement Fund) - Provides for the collection of a flood control fee and provides additional authority for county flood control and the development of comprehensive flood control management plans. A county may act to control flooding under the authority of this statute without forming a special purpose district.
- Ch. 86.13 RCW - Joint Flood Control - Provides authority and procedures for joint flood control by two counties where a river forms a boundary between the counties or where the river waters alternate between counties with potential for flood damage in both counties.
- Ch.86.16 RCW - Floodplain Management - A Floodplain Management Ordinance approved by the Department of Ecology is required of a community to qualify for the National Flood Insurance Program
- Ch. 86.24 RCW - Flood Control by State in Cooperation with Federal Agencies, Etc.
- Ch. 86.26 RCW - State Participation in Flood Control Maintenance
- RCW 86.26.050 - Projects in which state will participate -- Allocation of funds - Requires Department of Ecology approved the floodplain management activities of the county, city, or town having planning jurisdiction for funding of any flood control maintenance projects through the state's Flood Control Assistance Account
- Ch. 173-145 WAC - Administration of the Flood Control Assistance Account Program
- WAC 173-145-040 - Comprehensive Flood Hazard Management Plan (CFHMP) - Lists contents of the Comprehensive Flood Control Management Plan
- Ch. 173-158 WAC - Flood Plain Management - Adopted pursuant to chapter 86.16 RCW

National Flood Insurance Program (NFIP)

The U.S. Congress established the National Flood Insurance Program (NFIP) with the passage of the National Flood Insurance Act of 1968. NFIP allows property owners in participating communities to purchase insurance as a protection against flood losses in exchange for state and community floodplain management regulations that reduce future flood damages. Participation in the NFIP is optional, and is based on an agreement between communities and the federal government. If a community adopts and enforces a floodplain management ordinance to reduce future flood risk to new construction in floodplains, the federal government will make flood insurance available within the community as a financial protection against flood losses. This insurance is designed to provide an insurance alternative to disaster assistance to reduce the escalating costs of repairing damage to buildings and their contents caused by floods.

The emphasis of the NFIP floodplain management requirements is directed toward reducing threats to lives and the potential for damages to property in flood-prone areas. One key component in the Act is the restriction in place which prohibits FEMA from providing flood insurance to any individual property unless the community within which the property is located has adopted and enforces floodplain management regulations that meet or exceed the floodplain management criteria established within 44 Code of Federal Regulations (CFR) Part 60, *Criteria for Land Management and Use.*

As part of the NFIP, various funding opportunities are available for mitigation efforts.

Two elements which must be met by all jurisdictions within the local mitigation plan is the issue of Repetitive Loss Properties and Severe Repetitive Loss properties as they relate to floods only. These are defined as:

- *Repetitive Loss Properties*
  A repetitive loss property is one for which two or more losses of at least $1,000 each have been paid by the National Flood Insurance Program (NFIP) over a rolling 10-year period.
- *Severe Repetitive Loss*
  An SRL property is a residential property that is covered under an NFIP flood insurance policy and:
  1. That has at least four NFIP claim payments (including building and contents) over $5,000 each, and the cumulative amount of such claims payments exceeds $20,000; or
  2. For which at least two separate claims payments (building payments only) have been made with the cumulative amount of the building portion of such claims exceeding the market value of the building.
  3. For both (a) and (b) above, at least two of the referenced claims must have occurred within any 10-year period and must be greater than 10 days apart.

Repetitive Loss/Severe Repetitive Loss Properties by County as of March 2018

Jurisdiction	SRL Properties	RL Properties
Adams		0
Asotin		0
Benton	2	24
Chelan		17
Clallam	2	14

Repetitive Loss/Severe Repetitive Loss Properties by County as of March 2018		
Jurisdiction	SRL Properties	RL Properties
Clark		15
Columbia		6
Cowlitz	14	121
Douglas		0
Ferry		0
Franklin		0
Garfield		0
Grant		0
Grays Harbor	7	164
Island		27
Jefferson		10
King	27	824
Kitsap		4
Kittitas		46
Klickitat		0
Lewis	27	376
Lincoln		0
Mason	3	68
Okanogan		6
Pacific	1	19
Pend Oreille	1	5
Pierce	8	240
San Juan		0
Skagit	20	325
Skamania		2
Snohomish	27	600
Spokane	1	8
Stevens		0
Thurston	4	70
Wahkiakum	2	36
Walla Walla		4
Whatcom	1	97
Whitman		9

EMD and Ecology prioritize SRL and RL properties for mitigation, either through buyout or acquisition, using programs such as Hazard Mitigation Grant Program (HMGP), Flood Mitigation Assistance (FMA), and state-dedicated fund sources such as Floodplains by Design or the Flood Control Assistance Account Program, when available.

In addition to providing flood insurance and reducing flood damages through floodplain management regulations, the NFIP identifies and maps the Nation's floodplains. Mapping flood hazards creates broad-based awareness of the flood hazards and provides the data needed for floodplain management programs and to actuarially rate new construction for flood insurance. Recently, this mapping initiative has taken a new step toward providing a more reliable mapping system with the creation of RiskMAP (discussed in greater detail below).

The Homeowners' Flood Insurance Affordability Act of 2015 made changes to the insurance rate structure of the NFIP, including:

- Ending insurance rate subsidies in such a manner that rates do not go up by more than 18 percent per year.
- Implementing annual surcharges until subsidies are eliminated.
- Increase assessments for the reserve fund.
- Increasing rates for pre-FIRM buildings that have been substantially improved or substantially damaged.

The table below lists the top 20 Washington communities by policy count and Community Rating System (CRS) class (as of May 2017)

Policy County and CRS Rating for Top 20 Communities (as of May 2017)

Community	# Policies	CRS Class
Skagit County	2532	6
King County	2333	2
Pierce County	1830	2
Snohomish County	1792	5
Whatcom County	1137	6
City of Burlington	1113	5
Lewis County	1059	6
Island County	918	-
City of Kent	845	6
City of Hoquiam	843	-
City of Mount Vernon	836	6
City of Seattle	786	-
City of Centralia	774	6
Thurston County	717	2
Pacific County	697	-
City of Aberdeen	678	-
Yakima County	667	8
Cowlitz County	666	-
Clark County	636	5
City of Ocean Shores	591	-

NFIP Claim Counts in Washington for Top 20 Jurisdictions 1978 2018

Jurisdiction	Claim Count	Claim Amount (Total)
Snohomish County	1,335	$23,547,188.71
King County	1,241	21,938,236.49
City of Snoqualmie (King County)	963	18,140,795.40
Lewis County	750	22,979,058.50
City of Centralia (Lewis County)	735	26,012,105.26
Skagit County	711	7,410,010.73
Pierce County	551	11,825,884.11
City of Chehalis (Lewis County)	514	28,128,928.57
Cowlitz County	445	10,439,008.98
City of Aberdeen (Grays Harbor County)	333	2,824,658.75
Whatcom County	297	3,735,610.61
Thurston County	239	3,588,197.27
City of Hoquiam (Grays Harbor County)	237	3,658,794.40
Yakima County	235	1,748,992.97
Mason County	231	3,825,133.46
City of Seattle (King County)	227	2,162,695.25
Town of Hamilton (Skagit County)	227	3,955,758.59
Grays Harbor County	226	4,695,244.31
Island County	218	2,450,123.58
Kittitas County	196	2,271,686.79

Please note that claims for the county include unincorporated areas only.

Community Rating System

The National Flood Insurance Program's Community Rating System (CRS) was implemented in 1990 as a voluntary program, which recognizes and encourages community floodplain management activities that exceed the minimum NFIP standards. The National Flood Insurance Reform Act of 1994 codified the Community Rating System in the NFIP.

With CRS, flood insurance premium rates are discounted to reflect the reduced flood risk resulting from the community actions meeting the three goals of the CRS:

- Reduce flood losses
- Facilitate accurate insurance rating
- Promote the awareness of flood insurance

The more a jurisdiction does in exceeding NFIP standards, the more points they earn. These points are then utilized to establish the jurisdictions CRS class. There are ten CRS classes. Class one (1) requires the most credit points and gives the largest premium reduction; class 10 receives no premium reduction. For CRS participating communities, flood insurance premium rates are discounted in increments of 5%; i.e., a Class 1 community would receive a 45 percent premium discount, while a Class 9 community would receive a 5 percent discount, and as indicated above, a Class 10 is not participating in the CRS and receives no discount.

The CRS classes for local communities are based on 18 creditable activities, organized under four categories:

1. Public Information
2. Mapping and Regulations
3. Flood Damage Reduction
4. Flood Preparedness.

The table below describes the credit points earned, classification awarded and premium reductions given for Washington communities in the National Flood Insurance Program Community Rating System. Three counties in Washington, Pierce, King, and Thurston, are three of the six class 2 entities nationwide.

Washington Communities in NFIP Program

Community Number	Community Name	CRS Entry Date	Current Effective Date	Class	percent Discount for Special Flood Hazard Area (SFHA)	percent Discount for non SFHA	Status (Current or Rescinded)
530073	Auburn, City of	10/1/92	05/1/08	5	25	10	C
530074	Bellevue, City of	10/1/92	05/1/06	5	25	10	C
530153	Burlington, City of	10/1/94	10/1/09	5	25	10	C
530076	Carnation, City of	10/1/14	10/1/14	7	15	5	C
530103	Centralia, City of	10/1/94	05/1/16	6	20	10	C
530104	Chehalis, City of	10/1/94	05/1/13	6	20	10	C
530024	Clark County	10/1/04	10/1/09	5	25	10	C
530051	Ephrata, City of	10/1/00	05/1/16	8	10	5	C
530200	Everson, City of	10/1/94	10/1/09	7	15	5	C
530201	Ferndale, City of	05/1/15	05/1/15	7	15	5	C
530140	Fife, City of	05/1/06	10/1/16	10	0	0	R
530166	Index, Town of	05/1/98	05/1/08	6	20	10	C
530079	Issaquah, City of	10/1/92	05/1/08	5	25	10	C
530080	Kent, City of	05/1/10	05/1/10	6	20	10	C
530071	King County	10/1/91	10/1/07	2	40	10	C
530095	Kittitas County	05/1/15	05/1/15	6	20	10	C

Washington Communities in NFIP Program							
Community Number	Community Name	CRS Entry Date	Current Effective Date	Class	percent Discount for Special Flood Hazard Area (SFHA)	percent Discount for non SFHA	Status (Current or Rescinded)
530156	La Conner, Town of	10/1/96	05/1/12	7	15	5	C
530102	Lewis County	10/1/94	05/1/14	6	20	10	C
530316	Lower Elwha/Klallam Tribe	10/1/00	10/1/16	10	0	0	R
530331	Lummi Nation	05/1/10	10/1/14	7	15	5	C
530169	Monroe, City of	10/1/91	05/1/06	5	25	10	C
530158	Mount Vernon, City of	05/1/97	10/1/12	6	20	10	C
530085	North Bend, City of	10/1/95	05/1/06	6	20	10	C
530143	Orting, City of	05/1/08	05/1/13	5	25	10	C
530138	Pierce County	10/1/95	05/1/12	2	40	10	C
530087	Redmond, City of	05/1/16	05/1/16	5	25	10	C
530088	Renton, City of	10/1/94	10/1/14	5	25	10	C
530151	Skagit County	05/1/98	10/1/15	6	20	10	C
535534	Snohomish County	05/1/06	05/1/15	5	25	10	C
530090	Snoqualmie, City of	10/1/92	05/1/02	5	25	10	C
530173	Sultan, City of	10/1/03	10/1/13	6	20	10	C
530204	Sumas, City of	10/1/93	05/1/13	6	20	10	C
530188	Thurston County	10/1/00	10/1/16	2	40	10	C
530193	Wahkiakum County	10/1/07	10/1/07	8	10	5	C
530067	Westport, City of	10/1/09	10/1/14	8	10	5	C
530198	Whatcom County	10/1/96	10/1/06	6	20	10	C
530217	Yakima County	10/1/07	10/1/07	8	10	5	C

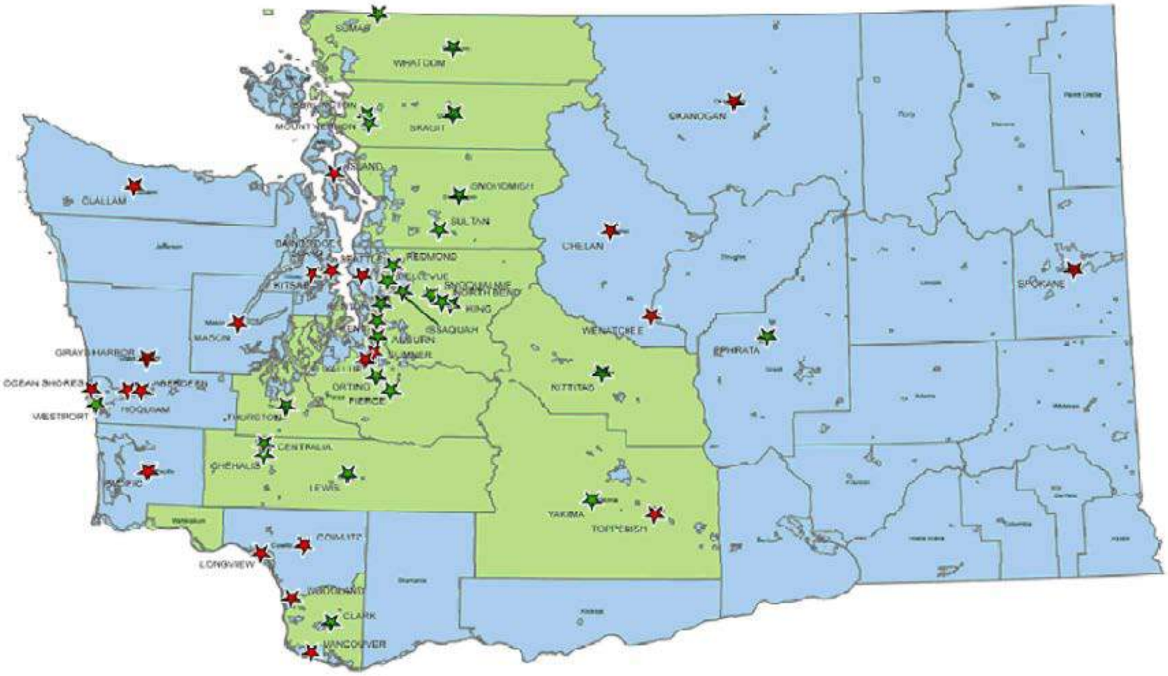


FIGURE 1: TOP 50 COMMUNITIES BY POLICY COUNT AND CRS PARTICIPATION (GREEN = PARTICIPATION)

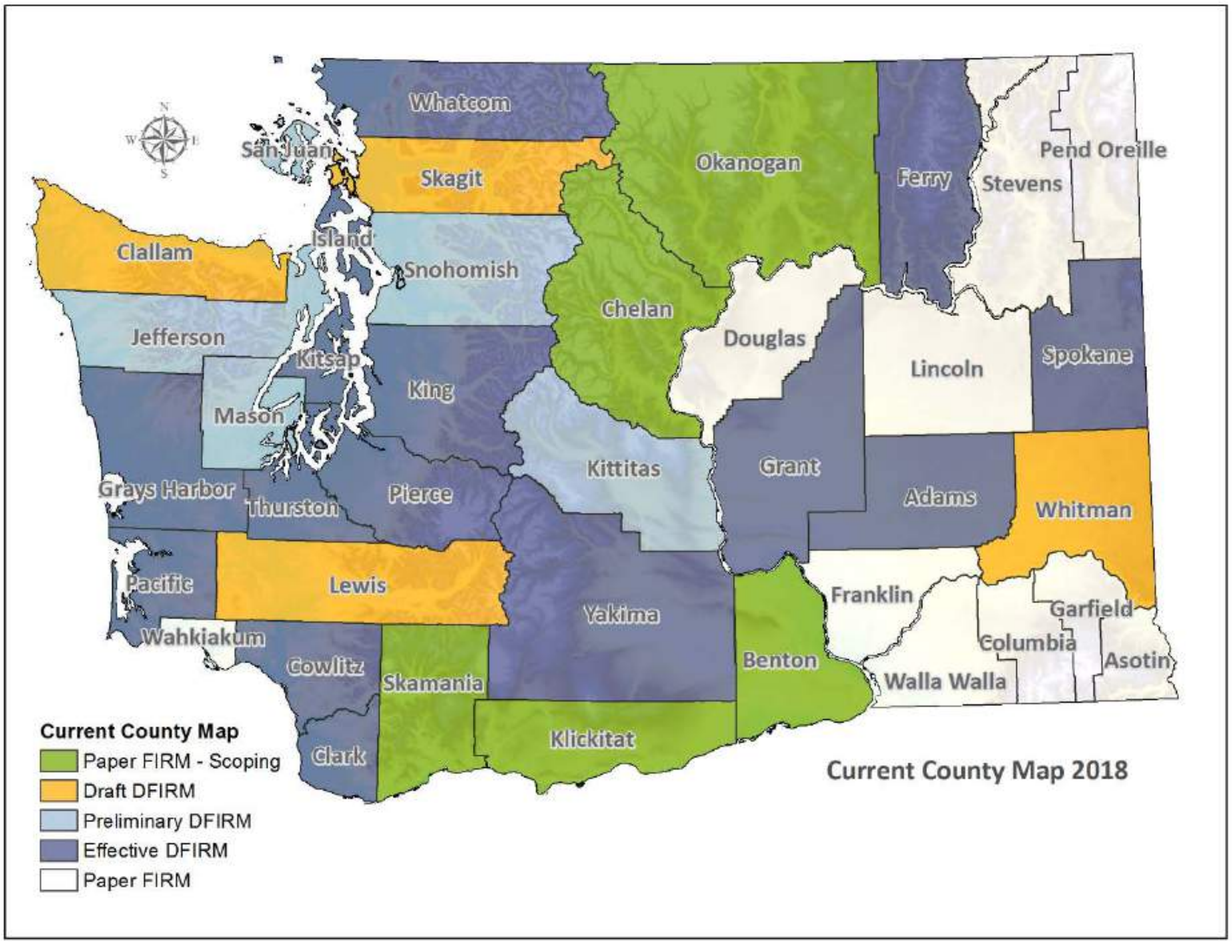


FIGURE F 1: FLOOD INSURANCE RATE MAP UPDATE STATUS

Risk MAP (Risk Mapping Assessment and Planning)

Flood risk analyses depend on reliable mapping. Mitigation planning also relies heavily on these maps and assessments. In the past, lack of funding permitted some maps to age over twenty and twenty-five years, resulting in unrealistic representation of local flood hazard. In recent years, map modernization significantly improved the horizontal accuracy of the flood hazard maps and made some focused improvements in base flood elevations. Figure F1 provides the status of updates to digital floodplain maps, and the table below provides the details of current floodplain maps utilized for flood hazard delineation in Washington counties.

Flood Insurance Rate Map Status				
County	**Project Status**	**Project Type**	**Current Map**	**Map Date**
Adams			Effective DFIRM	Jan-09
Asotin			Paper FIRM	Jan-88
Benton	Discovery	Countywide	Paper FIRM - Scoping	Jul-82
Chelan	Discovery	Countywide	Paper FIRM - Scoping	Sep-04
Clallam	Draft	Countywide Coastal	Draft DFIRM	Feb-01

Clark			Effective DFIRM	Sep-12
Columbia			Paper FIRM	Jul-00
Cowlitz			Effective DFIRM	Dec-15
Douglas			Paper FIRM	May-82
Ferry			Effective DFIRM	May-06
Franklin			Paper FIRM	May-80
Garfield			Paper FIRM	Nov-77
Grant			Effective DFIRM	Feb-09
Grays Harbor	Risk Assessment	Countywide Coastal	Effective DFIRM	Feb-17
Island	Risk Assessment	Coastal	Effective DFIRM	Feb-07
Jefferson	Preliminary	Countywide Coastal	Preliminary DFIRM	Jul-82
King	Risk Assessment	Coastal Riverine	Effective DFIRM	Apr-05
Kitsap	Risk Assessment	Coastal	Effective DFIRM	Nov-10
Kittitas	Preliminary	Countywide	Draft DFIRM	Dec-99
Klickitat	Discovery	Riverine	Paper FIRM - Scoping	Jul-81
Lewis			Draft DFIRM	Jul-06
Lincoln			Paper FIRM	Sep-88
Mason	Preliminary	Countywide Coastal	Preliminary DFIRM	Dec-98
Okanogan	Discovery	Countywide	Paper FIRM - Scoping	Feb-81
Pacific		Countywide Coastal	Effective DFIRM	Sep-85
Pend Oreille			Paper FIRM	Mar-02
Pierce	Risk Assessment	Countywide Coastal	Effective DFIRM	Aug-88
San Juan	Preliminary	Countywide Coastal	Preliminary DFIRM	Mar-91
Skagit			Draft DFIRM	Sep-89
Skamania	Discovery	Riverine	Paper FIRM - Scoping	Aug-86
Snohomish	Preliminary	Countywide Coastal	Preliminary DFIRM	Sep-05
Spokane		Countywide	Effective DFIRM	Jul-10
Stevens			Paper FIRM	Aug-96
Thurston	Risk Assessment	Coastal	Effective DFIRM	Oct-12
Wahkiakum			Paper FIRM	Sep-90
Walla Walla			Paper FIRM	Mar-81
Whatcom	Risk Assessment	Coastal Riverine	Effective DFIRM	Nov-07

Whitman	Draft	Countywide	Draft DFIRM	May-80
Yakima	Risk Assessment	Countywide	Effective DFIRM	Jul-12

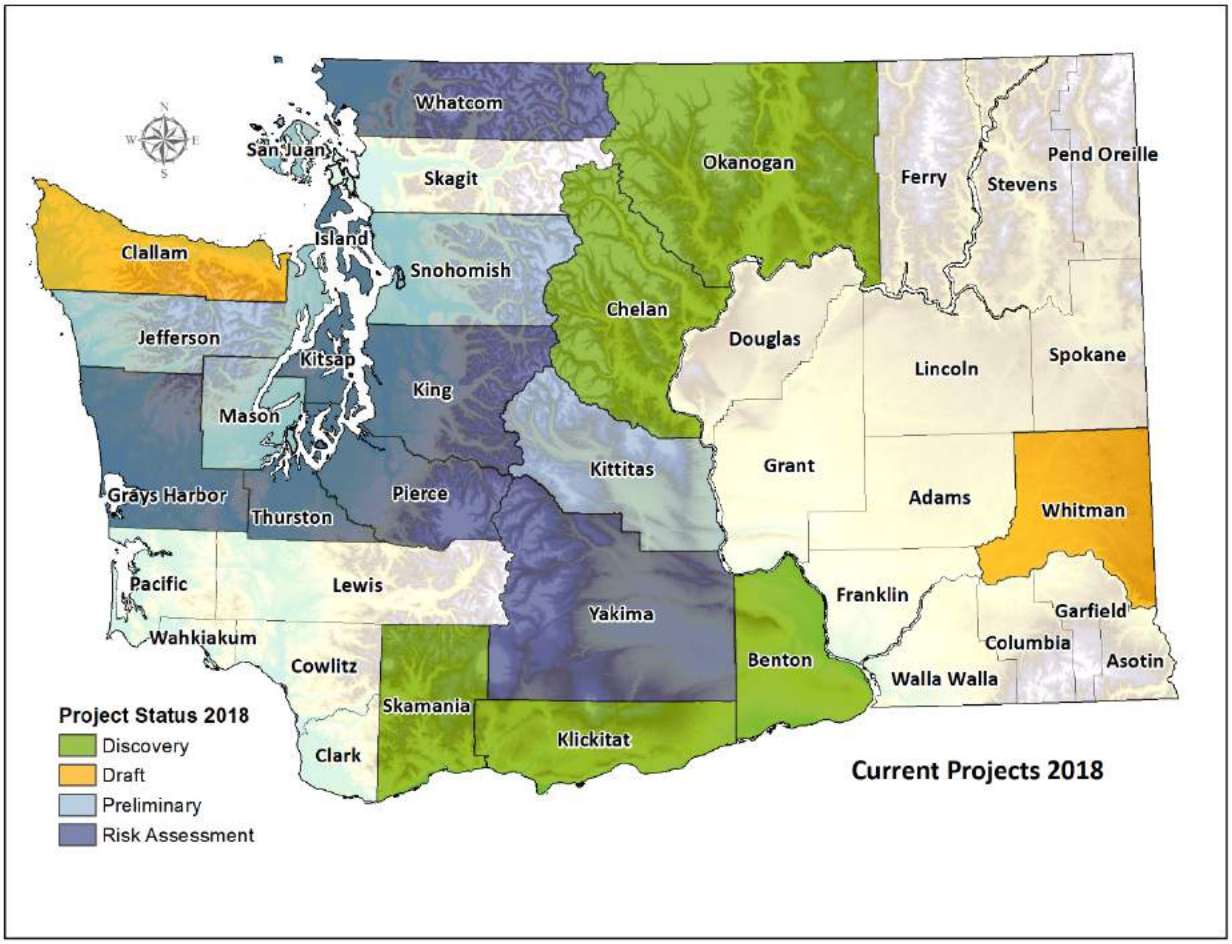
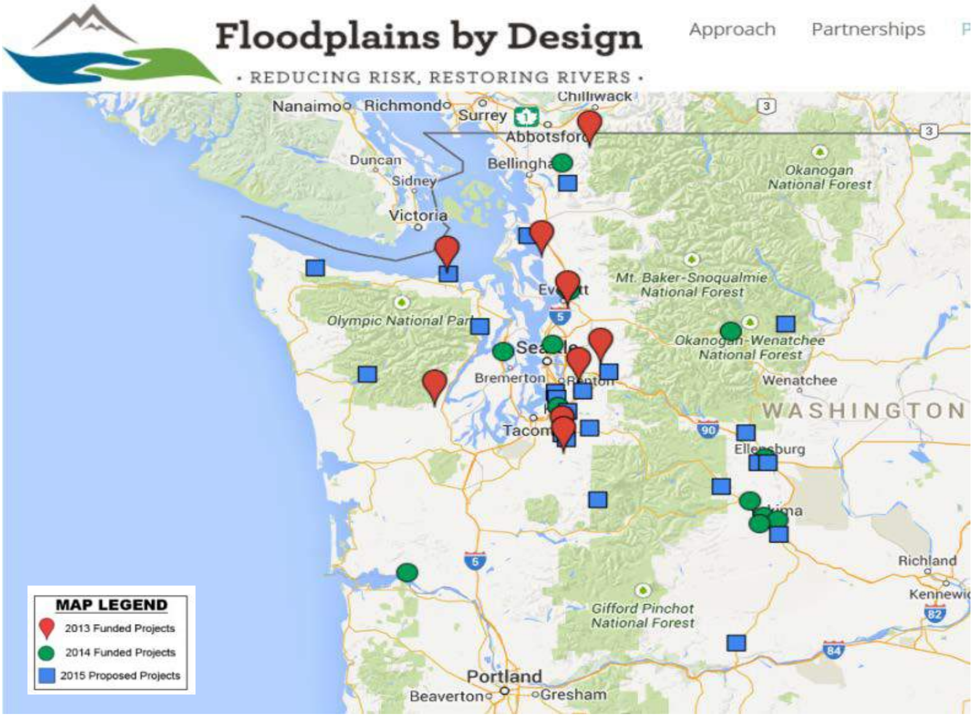


FIGURE F2: RISKMAP PROJECT STATUS

Floodplains by Design

Floodplains by Design is a new approach designed to integrate flood hazard reduction with ecosystem benefits and help leverage investments from other funding sources (Figure F2). Washington Department of Ecology is working with local project proponents to prepare a proposed FbD funding list for future funding. This list will support Ecology's request to continue FbD funding at the $50 million level in the FY 2015-2017 State budget.



Past Occurrences and Future Likelihood

Since 1953 Washington State received 28 flood related disaster declarations. Most of these major flood events have occurred between the months of December and March (Figure F3).

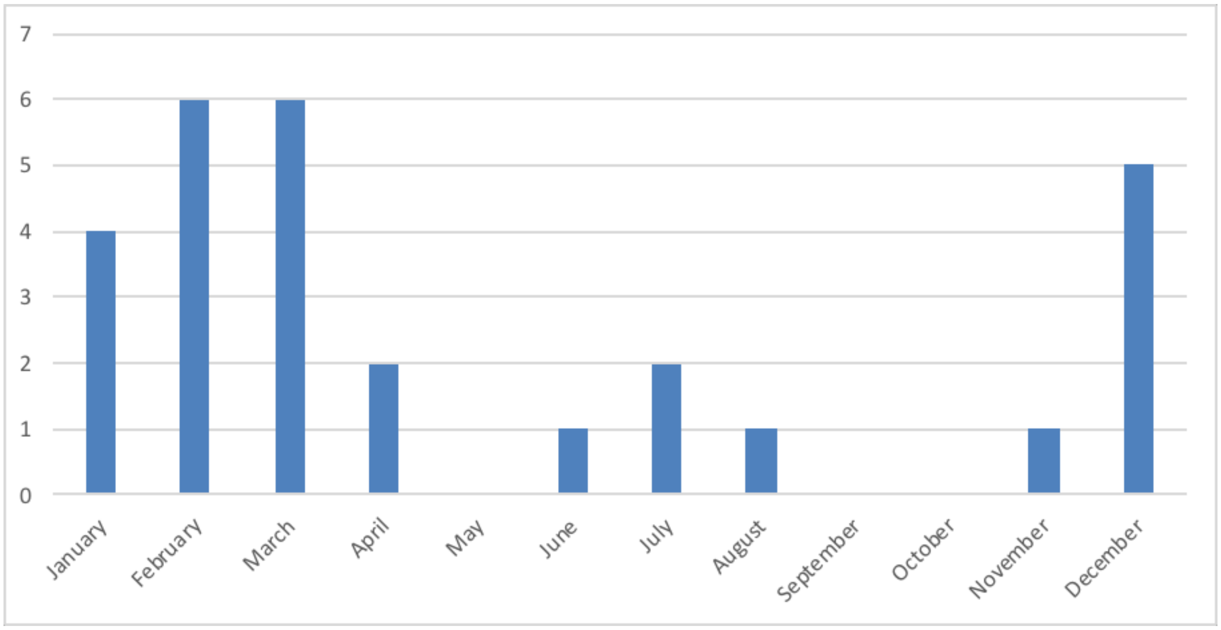


FIGURE F 4: MONTHLY DISTRIBUTION OF DISASTER DECLARATIONS (1953-2017)

King and Lewis counties each have experienced the most major flooding events (13), while Adams and Ferry counties have only experienced 1 major flooding declaration since 1953.

Flood Disaster Declarations (1953 2017)

County	Major Flooding Disaster
King County	13
Lewis County	13
Grays Harbor County	12
Snohomish County	10
Thurston County	10
Cowlitz County	9
Pierce County	9
Wahkiakum County	9
Mason County	8
Pacific County	8
Whatcom County	8
Yakima County	8
Benton County	7
Jefferson County	7
Skagit County	7
Clallam County	6
Kitsap County	6
Kittitas County	6
Skamania County	6
Whitman County	6
Columbia County	5
Garfield County	5
Klickitat County	5
Asotin County	4
Clark County	4
Spokane County	4
Chelan County	3
Lincoln County	3
Pend Oreille County	3
Statewide	3
Stevens County	3
Douglas County	2
Island County	2
Okanogan County	2
San Juan County	2
Walla Walla County	2
Adams County	1
Ferry County	1

The following is a list of major floods that occurred between 1953 and 2017. It is a brief history of past flood events for which documentation is readily available and provides a good snapshot of the extent of the flood problem in Washington.

- Washington Severe Winter Storms, Flooding, Landslides, and Mudslides (DR-4309) | Incident period: January 30, 2017 to February 22, 2017 | Major Disaster Declaration declared on April 21, 2017
- Washington Severe Winter Storm, Straight-Line Winds, Flooding, Landslides, Mudslides, and a Tornado (DR-4253) | Incident period: December 01, 2015 to December 14, 2015 | Major Disaster Declaration declared on February 02, 2016
- Washington Severe Winter Storm, Landslides, Mudslides, and Flooding (DR-1817) | Incident period: January 06, 2009 to January 16, 2009 | Major Disaster Declaration declared on January 30, 2009
- Washington Flooding (DR-1252) | Incident period: May 26, 1998 to May 29, 1998 | Major Disaster Declaration declared on October 05, 1998
- Washington Snowmelt/Flooding (DR-1182) | Incident period: April 10, 1997 to June 30, 1997 | Major Disaster Declaration declared on July 21, 1997
- Washington Severe Storms/Flooding/Landslides/Mudslides (DR-1172) | Incident period: March 18, 1997 to March 28, 1997 | Major Disaster Declaration declared on April 02, 1997
- Washington Severe Storms/Flooding (DR-1100) | Incident period: January 26, 1996 to February 23, 1996 | Major Disaster Declaration declared on February 09, 1996
- Washington High Tides, Severe Storm (DR-896) | Incident period: December 20, 1990 to December 31, 1990 | Major Disaster Declaration declared on March 08, 1991
- Washington Flooding, Severe Storm (DR-883) | Incident period: November 09, 1990 to December 20, 1990 | Major Disaster Declaration declared on November 26, 1990
- Washington Flooding, Severe Storm (DR-852) | Incident period: January 06, 1990 to January 14, 1990 | Major Disaster Declaration declared on January 18, 1990
- Washington Heavy Rains, Flooding, Mudslides (DR-822) | Incident period: March 08, 1989 to March 17, 1989 | Major Disaster Declaration declared on April 14, 1989
- Washington Severe Storms, Flooding (DR-784) | Incident period: November 22, 1986 to November 29, 1986 | Major Disaster Declaration declared on December 15, 1986
- Washington Severe Storms, Flooding (DR-769) | Incident period: May 20, 1986 | Major Disaster Declaration declared on July 26, 1986
- Washington Heavy Rains, Flooding, Landslides (DR-762) | Incident period: February 22, 1986 to February 24, 1986 | Major Disaster Declaration declared on March 19, 1986
- Washington Severe Storms, Flooding (DR-757) | Incident period: January 16, 1986 to January 19, 1986 | Major Disaster Declaration declared on February 15, 1986
- Washington Severe Storms, High Tides, Flooding (DR-676) | Incident period: January 27, 1983 | Major Disaster Declaration declared on January 27, 1983
- Washington Severe Storms, High Tides, Mudslides, Flooding (DR-612) | Incident period: December 31, 1979 | Major Disaster Declaration declared on December 31, 1979
- Washington Severe Storms, Mudslides, flooding (DR-545) | Incident period: December 10, 1977 | Major Disaster Declaration declared on December 10, 1977
- Washington Severe Storms, Flooding (DR-492) | Incident period: December 13, 1975 | Major Disaster Declaration declared on December 13, 1975

- Washington Severe Storms, Snowmelt, flooding (DR-414) | Incident period: January 25, 1974 | Major Disaster Declaration declared on January 25, 1974
- Washington Severe Storms, Flooding (DR-334) | Incident period: June 10, 1972 | Major Disaster Declaration declared on June 10, 1972
- Washington Heavy Rains, Flooding (DR-328) | Incident period: March 24, 1972 | Major Disaster Declaration declared on March 24, 1972
- Washington severe storms, Flooding (DR-322) | Incident period: February 01, 1972 | Major Disaster Declaration declared on February 01, 1972
- Washington Heavy Rains, Melting Snow, Flooding (DR-300) | Incident period: February 09, 1971 | Major Disaster Declaration declared on February 09, 1971
- Washington Heavy Rains & Flooding (DR-185) | Incident period: December 29, 1964 | Major Disaster Declaration declared on December 29, 1964
- Washington Floods (DR-146) | Incident period: March 02, 1963 | Major Disaster Declaration declared on March 02, 1963
- Washington Floods (DR-70) | Incident period: March 06, 1957 | Major Disaster Declaration declared on March 06, 1957
- Washington Flood (DR-50) | Incident period: February 25, 1956 | Major Disaster Declaration declared on February 25, 1956
- Washington Floods (DR-70) | Incident period: March 06, 1957 | Major Disaster Declaration declared on March 06, 1957

Based on the SHELDUS database, flooding events since 1960 have resulted in cumulative property losses worth almost $2 billion (2016 $). Similar to national trends, floods have primarily resulted in increasing property damages, whereas the injuries and fatalities have been limited in Washington State. Lewis county experienced the highest amount of property losses during this period with Yakima, Jefferson, Clallam, Wahkiakum, Grays Harbor, Cowlitz, Kitsap, Mason, Thurston, and Pacific counties with estimated property losses greater than $100 million each. Every county in Washington State has been part of a disaster declaration due to flooding.

Flooding Events (1960 2017)			
County Name	**Total Property Damage ($2016)**	**Total Injuries**	**Total Fatalities**
Adams	346363	0	0
Asotin	768214	0	0
Benton	1650389	0	0
Chelan	21067008	0	1
Clallam	114330500	0	1
Clark	99177565	0	0
Columbia	350232	0	0
Cowlitz	116786402	0	0
Douglas	8345824	0	0
Ferry	5418337	0	0

Flooding Events (1960 2017)

County Name	Total Property Damage ($2016)	Total Injuries	Total Fatalities
Franklin	333454	0	0
Garfield	361234	0	0
Grant	8419348	0	0
Grays Harbor	115944606	0	1
Island	15252340	0	0
Jefferson	113972578	0	0
King	77220221	1	6
Kitsap	122006698	0	1
Kittitas	33841964	0	0
Klickitat	82670	0	0
Lewis	193841018	0	4
Lincoln	972757	0	0
Mason	122445661	0	1
Okanogan	35253534	0	3
Pacific	133895611	0	0
Pend Oreille	923308	0	0
Pierce	52726773	0	1
San Juan	7198369	0	0
Skagit	34846603	2	4
Skamania	15988373	0	0
Snohomish	49858191	1	0
Spokane	5844191	0	0
Stevens	787681	0	0
Thurston	123673965	0	0
Wahkiakum	115598290	0	0
Walla Walla	89314227	0	0
Whatcom	30976914	0	0
Whitman	3743289	0	0
Yakima	106597198	2	0
Grand Total	1980161902	7	23

Between 1960 and 2017, the state has experienced at least one significant flooding event each year. In 28 of these years, there have been multiple significant flooding events (2 or more), and 29 times the state experienced more 10 flooding events in one year. Since 2000, the state has experienced multiple flooding events annually, with the most happening in year 2003 (36 flooding events). Based on the past records (since 1960) the likelihood of a major flooding in any given year is 0.43. However, based on the recent data since 2000, the likelihood of a major flooding event in any given year has increased to 1.0, that is, at least one major flooding event may be expected annually. Based on the same time period, the probability of multiple flooding events (more than 10) in any given year is estimated to be 0.81.

Years with at least One Major Flooding Event (1960 2017)

Year	Total Major Flood Events
1963	8
1965	39
1967	11
1971	7
1972	72
1975	33
1980	10
1982	18
1983	9
1985	1
1986	29
1987	36
1989	22
1990	97
1991	44
1992	6
1993	34
1995	29
1996	3
1997	13
1998	19
1999	18
2000	3
2001	18
2002	13
2003	36
2004	29
2005	4
2006	16
2007	8
2008	4
2009	24
2010	13
2011	24

Years with at least One Major Flooding Event (1960 2017)	
Year	**Total Major Flood Events**
2012	19
2013	12
2014	11
2015	19
2016	10
Grand Total	821

Source: Hazards & Vulnerability Research Institute (2017). The Spatial Hazard Events and Losses Database for the United States, Version 16.0 [Online Database]. Columbia, SC: University of South Carolina. Available from http://www.sheldus.org

Although floods can happen at any time during the year, there are typical seasonal patterns for flooding in Washington State, based on the variety of natural processes that cause floods:

- Heavy rainfall on wet or frozen ground, before a snow pack has accumulated, typically cause fall and early winter floods.
- Rainfall combined with melting of the low-elevation snow pack typically cause winter and early spring floods. Of particular concern is the phenomenon known as an atmospheric river, a warm and wet flow of subtropical air originating near Hawaii which can produce multi-day storms with copious rain and very high freezing levels.
- Late spring floods in Eastern Washington result primarily from melting of the snow pack.
- Thunderstorms typically cause flash floods during the summer in Eastern Washington; on rare occasions, thunderstorms embedded in winter-like rainstorms cause flash floods in Western Washington.

Development in or near floodplains also increases the likelihood of flooding. New developments on or adjacent to a flood plain add structures and people in flood areas, and new construction alters surface water flows by diverting water to new courses or increases the amount of water that runs off impervious pavement and roof surfaces. This second effect diverts waters to places previously safe from flooding. The effect has been seen in recent disasters in the Gulf Coast, where areas previously out of the floodplain experienced severe inundation after years of heavy population growth and development.

Climate changes is altering seasonal patterns. Many of the state's Cascade drainages are changing from snow/rain dominated systems to rain dominated ones. The Chehalis River is one of the few rivers that does not flow from the Cascades and reflects a rain dominated system.

The change has dramatic implications for the state. As these changing drainages become increasingly rain dominated systems, they are not expected to carry greater annual flows. Flows now distributed over two peak periods will come during the winter months. Summer flows will be reduced as more precipitation falls as rain and not snow thereby eliminated summer storage. Increases in winter floods will increase the frequency of flooding and mobilize more sediment.

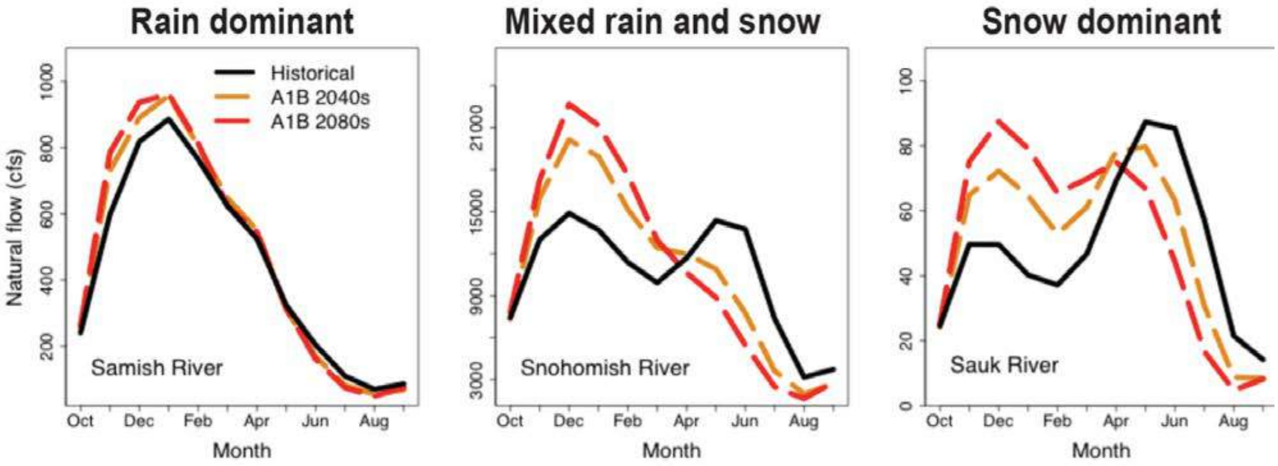


FIGURE F 5: STREAMFLOW IS PROJECTED TO INCREASE IN WINTER AND DECREASE IN SUMMER AND CHANGES ARE GREATEST FOR WATERSHEDS LOCATED NEAR THE CURRENT SNOW LINED. (DATA SOURCE: DOWNSCALED HYDROLOGIC PROJECTIONS BY HAMLET ET AL. 2013)

Relationship to other Hazards

Earthquakes can damage water infrastructure and cause tsunamis. Storm surge and tsunamis can cause flooding along coastlines and rivers. Rising seas and shifting weather patterns worsens flooding. Volcanoes can trigger lahars that block rivers, leading to flooding in the surrounding. Additionally, wildfires can worsen flooding by reducing the capacity for the ground to absorb water. Landslides are also often caused by heavy rainfall and floods.

Floods can also influence other hazards, both natural and human-caused. Flood events can lead to failures of dams, levees, or canals. Conversely, a flood event could help to lessen the hazards of both wildfire and drought, if only for a short time period. Most of the natural hazard events discussed in this plan can be exacerbated in some way or another by a flood event. Flood impacts on infrastructure and facilities could initiate a hazardous material or radiological release, or a cyber-disruption. Standing water left after a flood event could increase the susceptibility for a pandemic event to occur.

Our changing climate is altering the state's rivers. The change is occurring and will continue proportional to the emission of as greenhouse gasses. The change will not be linear but will occur as thresholds are crossed.

Flood Risk Assessment

For this analysis, flooding was largely defined by that described on FEMA Flood Insurance Rate Maps (FIRMs). A distinction was not generally made between riverine, surface or flash flooding. The flood hazard risk assessment is estimated for each of the census tracts. In this risk analysis both riverine and coastal flooding areas have been included. The areas designated at 1 percent and 0.2 percent chance of annual flooding were mapped based on the statewide GIS layer consisting of FEMA effective data from the National Flood Hazard Layer, preliminary data from FEMA's preliminary data site, and the Q3 layer for areas with paper maps, provided by the Washington Department of Ecology. Both zones cumulatively have been used to map the flooding hazard in the State.

The U.S. Department of Homeland Security (DHS) through FEMA and the NFIP are responsible for mapping floodplains. The NFIP is an insurance program and insurance rate determinations require that existing risks be mapped. For this reason, the FEMA maps are referred to as Flood Insurance Risk Maps (FIRMs) and must reflect current conditions determined at the time the engineering underlying these maps were completed. FIRMS cannot reflect future condition. For this reason, the designated 1 percent and .2 percent floodplain are out of date the day they are printed. In stable floodplains these maps can remain accurate for a very long time, but this is not the case for dynamic floodplains.

Floodplains draining urbanizing areas will be change with urban impermeable development as will those below wildland fire burnt landscapes. Also, as had been discussed previously, climate change is causing many of our rivers to change from snow/rain dominated system to rain systems. Winter storms are increasing in frequency and intensity. Floods with a reoccurrence interval of 1 percent in any given year, have a reoccurrence life of 50, 25 or 10 years. And, more sediment is being mobilized with more frequent flooding.

Many communities realize this deficiency and are mapping future conditions. The FEMA Risk Map program has also mapped future conditions. Such mapping cannot be used for insurance rating, but as long as the future map equal or exceeds the floodplain shown on the FIRM, it can be used for regulatory purposes.

FIGURE F 6: FLOOD HAZARD AREA IN THE STATE

(includes areas with 1 percent and 0.2 percent chance of annual flooding, both riverine and coastal. Data provided by Department of Ecology, WA.)

Area Exposure

The total designated area with 1 percent or 0.2 percent annual chance of flooding is less than 10 percent of the total area of the state. However, based on past flooding events, floods are likely to inundate much larger areas beyond the designated floodplain boundaries. Also, a number of these floodplain boundaries are in the process of updating and as such may not represent the real extent of flood hazard. Almost 45 percent of San Juan County is identified at risk from 1 percent chance of annual flooding (coastal flooding). In Island County, 30 percent of the area is included in flood zone with 1 percent annual chance of flooding. In Wahkiakum, Kitsap, Mason, Jefferson, Thurston, Skagit, Pacific, Clark, Pierce, and Whatcom counties, 10-15 percent of the county area lies within the flood zones with 1 percent and 0.2 percent chance of flooding annually.

Percentage of County Land Area with Flood Exposure		
County	1 percent Annual Chance of Flooding	0.2 percent Annual Chance of Flooding
Adams	2.99	0.00
Asotin	1.31	0.01
Benton	4.47	0.17
Chelan	1.35	0.19
Clallam	4.37	0.12
Clark	10.70	0.59
Columbia	2.21	0.11
Cowlitz	4.70	3.11
Douglas	0.58	2.46
Ferry	0.48	0.00
Franklin	3.83	0.11
Garfield	2.19	0.00
Grant	6.61	0.02
Grays Harbor	8.53	0.28
Island	29.71	0.04
Jefferson	11.76	0.04
King	4.44	0.23
Kitsap	14.68	0.05
Kittitas	3.21	0.13
Klickitat	3.07	0.01
Lewis	5.25	0.29
Lincoln	2.99	0.01
Mason	12.71	0.03
Okanogan	0.84	0.05
Pacific	10.86	0.25
Pend Oreille	3.01	0.00
Pierce	10.67	1.20
San Juan	44.36	0.00
Skagit	11.49	0.54
Skamania	1.60	0.00
Snohomish	6.74	0.13
Spokane	2.58	0.20
Stevens	3.60	0.05
Thurston	11.55	0.72
Wahkiakum	15.52	2.28
Walla Walla	4.51	0.17
Whatcom	10.54	0.16
Whitman	3.67	0.03
Yakima	2.04	0.16
Washington State	5.04	0.28

Population Exposure

Population exposure to tsunamis was estimated by overlaying the flood hazard layer over the 2011 developed areas derived from the land cover database. The 2017 estimated population for all census tracts was allocated to respective urban areas and the overlap with hazard exposure was estimated using spatial analysis in Geographic Information System (GIS). While most communities in Washington are exposed to flood hazards, overall less than 10 percent of the population resides in areas identified to be at risk from 1 percent annual chance of flooding. It is likely that this assessment may under represent the true nature of population exposure because the of spatial data limitations. In Skagit County, more than 50 percent of the population is located in areas identified to be at risk from flooding. While the overall population within the flood zones is not high, it is expected that there are a large number of people residing just to the outside of the designated flood zones because of the natural amenities that such areas offer. In large flood events, the number of persons affected is likely to higher than only those residing within the flood zones.

The state's changing climate is increasing those exposed to flooding.

Population Exposure to Flood Hazard				
County	Total Population (2017 Estimates)	Percentage of Total State Population	Estimated County Population Exposed to 1% Annual Chance of Flooding (in% values)	Estimated County Population Exposed to 0.2% Annual Chance of Flooding (in% values)
Adams	19870	0.27	0.66	0.00
Asotin	22290	0.30	1.30	0.29
Benton	193500	2.65	6.54	1.57
Chelan	76830	1.05	14.86	20.33
Clallam	74240	1.02	5.57	0.38
Clark	471000	6.44	4.52	1.16
Columbia	4100	0.06	16.34	50.85
Cowlitz	105900	1.45	13.80	24.60
Douglas	41420	0.57	5.96	41.47
Ferry	7740	0.11	27.86	0.00
Franklin	90330	1.24	8.48	0.21
Garfield	2200	0.03	72.00	0.20
Grant	95630	1.31	6.65	0.11
Grays Harbor	72970	1.00	18.17	0.52
Island	82790	1.13	6.17	0.25
Jefferson	31360	0.43	13.53	0.21
King	2153700	29.46	4.72	0.62
Kitsap	264300	3.62	1.95	0.17
Kittitas	44730	0.61	17.24	13.75
Klickitat	21660	0.30	9.43	0.05
Lewis	77440	1.06	17.31	1.62
Lincoln	10700	0.15	17.48	5.05

Population Exposure to Flood Hazard				
County	Total Population (2017 Estimates)	Percentage of Total State Population	Estimated County Population Exposed to 1% Annual Chance of Flooding (in% values)	Estimated County Population Exposed to 0.2% Annual Chance of Flooding (in% values)
Mason	63190	0.86	8.92	0.08
Okanogan	42110	0.58	20.32	10.14
Pacific	21250	0.29	8.86	0.74
Pend Oreille	13370	0.18	1.87	0.00
Pierce	859400	11.76	5.25	2.44
San Juan	16510	0.23	6.51	0.00
Skagit	124100	1.70	51.56	2.27
Skamania	11690	0.16	5.80	0.00
Snohomish	789400	10.80	8.44	0.25
Spokane	499800	6.84	1.85	1.61
Stevens	44510	0.61	5.10	0.35
Thurston	276900	3.79	6.45	0.95
Wahkiakum	4030	0.06	32.69	0.43
Walla Walla	61400	0.84	14.25	0.43
Whatcom	216300	2.96	15.71	0.64
Whitman	48640	0.67	12.25	2.08
Yakima	253000	3.46	15.47	2.72
Washington State	7310300	100.00	8.82	2.06

Vulnerable Population Exposure

The social vulnerability index was created for each of the census tracts using American Community Survey (ACS) 2011-2016 5-year data. Social vulnerability data was first overlaid with developed areas extracted from the 2011 land cover database. Tract level social vulnerability estimates were assigned to respective developed areas in each of the tracts. This data was then overlaid with flood hazard layer to identify socially vulnerable developed areas that overlap with flood hazard zones.

Overall less than 1 percent of the state's population is vulnerable and resides in flood hazard zones. In Yakima and Okanogan counties about 5 percent of the population is ranked medium or higher on social vulnerability and is in flood hazard zones. In all other counties, less than 5 percent of their population is both ranked medium or higher on social vulnerability index and is in flood hazard zones. However, it is estimated that almost three times this population resides in census tracts with flood hazard risks.

Vulnerable Population Exposure to Flood

County	Population (2017 Estimates)	Vulnerable Population			
		Exposed to 1% Annual Chance of Flooding		Exposed to 0.2% Annual Chance of Flooding	
		Estimated Population	As% of County Population	Estimated Population	As% of County Population
Adams	19870	131	0.66	0	0.00
Asotin	22290	0	0.00	64	0.29
Benton	193500	198	0.10	3039	1.57
Chelan	76830	327	0.43	15617	20.33
Clallam	74240	93	0.13	279	0.38
Clark	471000	486	0.10	5476	1.16
Columbia	4100	0	0.00	2085	50.85
Cowlitz	105900	1697	1.60	26051	24.60
Douglas	41420	302	0.73	17177	41.47
Ferry	7740	0	0.00	0	0.00
Franklin	90330	2934	3.25	190	0.21
Garfield	2200	0	0.00	0	0.00
Grant	95630	1023	1.07	110	0.11
Grays Harbor	72970	1030	1.41	382	0.52
Island	82790	0	0.00	209	0.25
Jefferson	31360	0	0.00	65	0.21
King	2153700	14286	0.66	13391	0.62
Kitsap	264300	0	0.00	438	0.17
Kittitas	44730	0	0.00	6150	13.75
Klickitat	21660	0	0.00	10	0.05
Lewis	77440	530	0.68	1258	1.62
Lincoln	10700	0	0.00	540	5.05
Mason	63190	394	0.62	48	0.08
Okanogan	42110	1697	4.03	4272	10.14
Pacific	21250	410	1.93	157	0.74
Pend Oreille	13370	0	0.00	0	0.00
Pierce	859400	2901	0.34	20930	2.44
San Juan	16510	0	0.00	0	0.00
Skagit	124100	3638	2.93	2815	2.27
Skamania	11690	0	0.00	0	0.00
Snohomish	789400	4945	0.63	1989	0.25
Spokane	499800	680	0.14	8046	1.61
Stevens	44510	43	0.10	155	0.35
Thurston	276900	266	0.10	2635	0.95
Wahkiakum	4030	0	0.00	17	0.43
Walla Walla	61400	0	0.00	262	0.43
Whatcom	216300	47	0.02	1389	0.64
Whitman	48640	90	0.18	1011	2.08
Yakima	253000	13556	5.36	6872	2.72
Washington State	7310300	56377	0.77	150738	2.06

Built Environment Exposure

The built environment exposure to flood is calculated using the General Building Stock data (2014) provided by FEMA that contains the building values for all structures in the census tracts. General building stock values used in this analysis are the total structure value of all buildings (except agricultural) in each census tract in 2014 dollars. Building values for all occupancy types were summed for each census tract using only structure values (not content values) and assigned to the developed areas within each tract. These maps were then overlaid on the flood hazard layer to estimate the general building stock value within the hazard exposure areas. Individual tract level estimates were aggregated to create the county level estimates.

Overall only a small proportion of the state general building stock is in flood hazard zones. However, in Garfield and Skagit Counties significant proportion of their building stock is in flood hazard zones. In San Juan and Island Counties, the top two counties with highest proportion of county area in flood hazard zones, only 6 percent of the respective county general building stock is in flood hazard zones.

Climate change is increasing building stock exposed to flood risks.

Built Environment Exposure to Floods

County	Total Value of General Building Stock (2014)	Exposed to 1% Annual Chance of Flooding		Exposed to 0.2% Annual Chance of Flooding	
		Estimated Value	As% of Total County Estimates	Estimated Value	As% of Total County Estimates
Adams	$253,615	$1,674	0.66	$0	0.00
Asotin	$1,061,235	$13,838	1.30	$3,029	0.29
Benton	$6,529,565	$427,049	6.54	$102,542	1.57
Chelan	$1,573,417	$233,833	14.86	$319,827	20.33
Clallam	$2,427,219	$135,119	5.57	$9,115	0.38
Clark	$32,074,170	$1,449,640	4.52	$372,920	1.16
Columbia	$533	$87	16.34	$271	50.85
Cowlitz	$4,992,730	$688,778	13.80	$1,228,175	24.60
Douglas	$1,211,949	$72,187	5.96	$502,593	41.47
Ferry	$1,521	$424	27.86	$0	0.00
Franklin	$1,867,499	$158,319	8.48	$3,925	0.21
Garfield	$437	$237	72.00	$0	0.20
Grant	$583,022	$38,756	6.65	$670	0.11
Grays Harbor	$1,162,104	$211,153	18.17	$6,086	0.52
Island	$2,895,464	$178,648	6.17	$7,312	0.25
Jefferson	$1,137,144	$153,906	13.53	$2,358	0.21
King	$362,698,022	$17,114,335	4.72	$2,255,076	0.62
Kitsap	$17,267,166	$336,617	1.95	$28,592	0.17
Kittitas	$530,126	$91,405	17.24	$72,884	13.75
Klickitat	$4,479	$422	9.43	$2	0.05
Lewis	$1,402,914	$242,871	17.31	$22,788	1.62
Lincoln	$87,198	$15,241	17.48	$4,404	5.05
Mason	$608,531	$54,274	8.92	$461	0.08

Built Environment Exposure to Floods

County	Total Value of General Building Stock (2014)	Exposed to 1% Annual Chance of Flooding		Exposed to 0.2% Annual Chance of Flooding	
		Estimated Value	As% of Total County Estimates	Estimated Value	As% of Total County Estimates
Okanogan	$59,252	$12,042	20.32	$6,011	10.14
Pacific	$125,715	$11,138	8.86	$927	0.74
Pend Oreille	$8,310	$156	1.87	$0	0.00
Pierce	$62,547,883	$3,284,563	5.25	$1,523,271	2.44
San Juan	$225,856	$14,702	6.51	$0	0.00
Skagit	$5,389,339	$2,778,966	51.56	$122,262	2.27
Skamania	$17,391	$1,008	5.80	$0	0.00
Snohomish	$52,406,666	$4,425,662	8.44	$132,069	0.25
Spokane	$31,281,088	$578,341	1.85	$503,566	1.61
Stevens	$325,218	$16,584	5.10	$1,129	0.35
Thurston	$9,798,392	$631,761	6.45	$93,230	0.95
Wahkiakum	$1,649	$539	32.69	$7	0.43
Walla Walla	$3,061,065	$436,139	14.25	$13,058	0.43
Whatcom	$15,241,051	$2,394,816	15.71	$97,855	0.64
Whitman	$1,385,430	$169,768	12.25	$28,802	2.08
Yakima	$7,986,979	$1,235,760	15.47	$216,935	2.72
Washington State	$630,231,344	$55,571,110	8.82	$12,995,333	2.06

All dollar values are in '0000s

Critical Infrastructure Exposure

Critical infrastructure facilities that lie within flood hazard zones will be directly impacted by flooding. While the nature and degree of impact will largely depend on the size of the flood event and the physical details of the facility, spatial overlay analysis can enable prioritization of site specific hazard mitigation studies. Location of 12 critical infrastructure facility types, including airports (23), communication towers (16097), dams (268), education facilities (5331), electric substations (1392), hospitals (147), power plants (146), public transit stations (60), railroad bridges (1619), railway stations (317), urgent care facilities (113), and weather radar stations (2), were derived from the Homeland Security Foundation Level Database (HIFLD). This data was overlaid with the flood hazard zones to identify facilities located in hazard areas. This analysis refers to point data and not critical infrastructure represented by networks such as roads and rail corridors. A number of major transportation corridors and other infrastructure networks will also be impacted by flooding. However, due to data limitations this analysis of infrastructure networks has not been undertaken.

Less than 6 percent of the critical infrastructure facilities in the state are in identified flooding zones. In Skagit and Wahkiakum Counties 23 percent of the critical infrastructure facilities in the county are in flood hazard zones. Skagit County has the maximum number of critical infrastructure facilities (109) in flood hazard zone, followed by King County with 74 facilities, which is only about 3 percent of all the critical facilities in King County. In Grays Harbor County, 21 percent of all the critical infrastructural facilities in the county are in flood hazard zones. It is important to undertake detailed individual assessment of the flood exposure to critical infrastructure facilities as damage to these facilities or the loss of function can lead to cascading events that will likely result in greater losses. This risk will increase as the climate changes.

Critical Infrastructure Exposure			
County	Number of Critical Infrastructure Facilities	In areas Exposed to 1% Annual Chance of Flooding	
		Number of Critical Infrastructure Facilities	Percent of Critical Infrastructure Facilities
Adams	206	7	3.40
Asotin	81	0	0.00
Benton	664	12	1.81
Chelan	507	29	5.72
Clallam	273	20	7.33
Clark	490	21	4.29
Columbia	88	2	2.27
Cowlitz	474	28	5.91
Douglas	290	5	1.72
Ferry	83	1	1.20
Franklin	270	15	5.56
Garfield	89	2	2.25
Grant	501	26	5.19
Grays Harbor	377	78	20.69
Island	104	1	0.96
Jefferson	197	4	2.03
King	2761	74	2.68
Kitsap	451	10	2.22
Kittitas	303	11	3.63
Klickitat	322	10	3.11
Lewis	374	51	13.64
Lincoln	237	13	5.49
Mason	152	16	10.53
Okanogan	359	13	3.62
Pacific	152	13	8.55
Pend Oreille	69	1	1.45
Pierce	1130	54	4.78
San Juan	98	3	3.06
Skagit	474	109	23.00
Skamania	145	9	6.21
Snohomish	787	60	7.62
Spokane	933	15	1.61
Stevens	211	7	3.32
Thurston	462	17	3.68
Wahkiakum	17	4	23.53
Walla Walla	273	6	2.20
Whatcom	613	47	7.67
Whitman	409	15	3.67
Yakima	601	38	6.32
Washington State	16027	847	5.28

State Operations and Facilities Exposure

The list of state owned (9415) and leased facilities (1039) was obtained from 2017 Facilities Inventory System Report produced by Office of Financial Management (detailed list included in Appendix). These facilities were geo-located based on the addresses provided in the facilities inventory report and then overlaid with flood hazard layer.

It is estimated that less than 5 percent of the state-owned facilities and state-leased facilities are in flood hazard zones. The highest number of state-owned facilities in the flood hazard zone is in King County (40) followed by Pierce County which has 35 state-owned facilities located in the flood hazard zones. However, they constitute less than 5 percent of the total state-owned facilities in each of these counties. In Skagit County, 53 percent of the state-leased facilities are in flood hazard zones. As such, direct exposure of state facilities to flooding hazard is low but proximity to flooded areas can also lead to loss of function. Flooding may prevent workers and visitors from reaching these facilities and may lead to shutdown of these facilities. These impacts are important and will need to be considered in local facility-level flood risk assessments.

Flood risks are increasing with climate change. Increased flooding will impact infrastructure directly as mentioned above, also indirect impacts such as road closures, and related business interruptions are expected to increase.

State Owned and Leased Facilities Exposure

County	State Owned Facilities	State Leased Facilities	In areas Exposed to 1% Annual Chance of Flooding			
			State Owned Facilities	Percent of State Owned Facilities	State Leased Facilities	Percent of State Leased Facilities
Adams	64	1	3	4.69	0	0.00
Asotin	90	6	8	8.89	0	0.00
Benton	159	30	7	4.40	0	0.00
Chelan	192	22	8	4.17	0	0.00
Clallam	183	12	12	6.56	1	8.33
Clark	229	23	9	3.93	0	0.00
Columbia	75	1	3	4.00	0	0.00
Cowlitz	128	18	12	9.38	0	0.00
Douglas	42	10	2	4.76	0	0.00
Ferry	32	3	2	6.25	0	0.00
Franklin	160	9	7	4.38	0	0.00
Garfield	21	0	2	9.52	0	0.00
Grant	252	15	8	3.17	3	20.00
Grays Harbor	224	13	15	6.70	6	46.15
Island	269	6	6	2.23	0	0.00
Jefferson	394	5	23	5.84	0	0.00
King	1120	226	40	3.57	8	3.54
Kitsap	269	15	7	2.60	0	0.00
Kittitas	348	11	15	4.31	0	0.00
Klickitat	110	10	7	6.36	0	0.00

State Owned and Leased Facilities Exposure						
County	State Owned Facilities	State Leased Facilities	In areas Exposed to 1% Annual Chance of Flooding			
			State Owned Facilities	Percent of State Owned Facilities	State Leased Facilities	Percent of State Leased Facilities
Lewis	163	13	8	4.91	4	30.77
Lincoln	58	0	5	8.62	0	0.00
Mason	244	7	5	2.05	0	0.00
Okanogan	179	10	18	10.06	1	10.00
Pacific	233	6	13	5.58	3	50.00
Pend Oreille	18	5	0	0.00	0	0.00
Pierce	865	54	35	4.05	1	1.85
San Juan	282	5	11	3.90	0	0.00
Skagit	286	15	12	4.20	8	53.33
Skamania	64	2	6	9.38	0	0.00
Snohomish	270	71	10	3.70	2	2.82
Spokane	571	121	24	4.20	0	0.00
Stevens	65	7	4	6.15	0	0.00
Thurston	431	166	16	3.71	0	0.00
Wahkiakum	22	0	0	0.00	0	0.00
Walla Walla	159	11	5	3.14	0	0.00
Whatcom	283	32	10	3.53	1	3.13
Whitman	566	9	23	4.06	1	11.11
Yakima	294	61	11	3.74	1	1.64
Washington State	9415	1031	412	4.38	40	3.88

First Responder Facilities Exposure

Locations of fire stations, law enforcement buildings, and emergency medical stations in the State were identified from the Homeland Security Foundation Level Database (HIFLD). Using ESRI ArcMap geocoding services 1,268 fire stations, 332 law enforcement agencies, and 1,162 EMS stations (including those co-located with fire stations) were located on the state map.

It is estimated that 5 percent of the fire stations, 8 percent of the law enforcement buildings, and 6 percent of the EMS facilities are in flood hazard zones. Skagit County has the most fire stations (7), and law enforcement buildings (4) in flood hazard zones. Skamania County has most EMS facilities (7) in flood hazard zone. Similar, to the state facilities, the overall number of facilities exposed to flood hazards is low. Detailed site level analysis is necessary to identify specific flooding risks to these facilities, including the risks that are likely to impact normal functioning and service delivery.

First Responder Facilities Exposure to Floods

County	Fire Station			Law Enforcement			EMS		
	Total Number of Facilities	In areas of Flood Exposure		Total Number of Facilities	In areas of Flood Exposure		Total Number of Facilities	In areas of Flood Exposure	
		Number of facilities	Percent Facilities		Number of facilities	Percent Facilities		Number of facilities	Percent Facilities
Adams	11	1	9.09	4	0	0.00	5	1	20.00
Asotin	3	0	0.00	4	1	25.00	2	0	0.00
Benton	29	0	0.00	7	0	0.00	27	0	0.00
Chelan	30	2	6.67	3	0	0.00	21	2	9.52
Clallam	22	1	4.55	5	0	0.00	24	2	8.33
Clark	40	1	2.50	13	0	0.00	40	1	2.50
Columbia	3	1	33.33	1	0	0.00	2	1	50.00
Cowlitz	25	1	4.00	8	0	0.00	17	0	0.00
Douglas	12	0	0.00	3	0	0.00	8	0	0.00
Ferry	12	0	0.00	3	0	0.00	5	0	0.00
Franklin	20	1	5.00	7	0	0.00	15	1	6.67
Garfield	2	1	50.00	1	0	0.00	1	0	0.00
Grant	50	3	6.00	15	4	26.67	28	2	5.51
Grays Harbor	32	6	18.75	9	3	33.33	20	2	7.14
Island	10	0	0.00	4	0	0.00	9	6	30.00
Jefferson	12	2	16.67	4	1	25.00	13	0	0.00
King	159	3	1.89	60	1	1.67	161	2	15.38
Kitsap	47	0	0.00	6	0	0.00	49	4	2.48
Kittitas	33	3	9.09	6	0	0.00	33	0	0.00
Klickitat	36	0	0.00	3	0	0.00	25	3	9.09
Lewis	51	6	11.76	12	2	16.67	50	0	0.00
Lincoln	10	5	50.00	4	2	50.00	9	5	10.00
Mason	46	5	10.87	3	0	0.00	47	5	55.56
Okanogan	27	0	0.00	7	0	0.00	17	5	10.64
Pacific	16	4	25.00	5	2	40.00	10	0	0.00
Pend Oreille	18	0	0.00	1	0	0.00	16	1	10.00
Pierce	99	1	1.01	29	1	3.45	101	0	0.00
San Juan	4	0	0.00	1	0	0.00	5	2	1.98
Skagit	39	7	17.95	6	4	66.67	40	0	0.00
Skamania	3	0	0.00	2	0	0.00	3	7	17.50
Snohomish	74	2	2.70	23	2	8.70	73	0	0.00
Spokane	52	1	1.92	10	0	0.00	50	2	2.74
Stevens	34	0	0.00	6	0	0.00	27	1	2.00
Thurston	47	1	2.13	17	0	0.00	55	0	0.00
Wahkiakum	9	2	22.22	1	0	0.00	5	1	1.82
Walla Walla	21	0	0.00	3	0	0.00	20	2	40.00
Whatcom	50	4	8.00	10	2	20.00	54	0	0.00
Whitman	24	2	8.33	8	1	12.50	22	4	7.41
Yakima	56	3	5.36	18	0	0.00	53	1	4.55
Grand Total	1268	69	5.44	332	26	7.83	1162	3	5.66

Washington State Risk Index for Floods (WaSRI-F)

The flood risk index (WaSRI-F) for each county is estimated as the average of the standardized rank of flood exposure assessment for county area, population, vulnerable populations, built environment, critical infrastructure facilities, state facilities and first responder facilities. The individual exposure assessment values were categorized into 5 classes (1: Low, 2: Medium-Low, 3: Medium, 4: Medium-High, and 5: High) using z-score transformation (standard deviations from the mean).

Classification Schema for Standardized Exposure Assessment Values

Standard Deviation	Classification Rank
>1	High (5)
0.50 to 1.0	Medium-High (4)
0.5 to -0.5	Medium (3)
-0.5 to -1	Medium-Low (2)
< -1.0	Low (1)

The flood risk index (WaSRI-F) is the mean of these individual exposure rankings. While similar assessments were also done for economic consequences (described in the next sections), these specific rankings were not included in the estimation of the flood risk index. Economic consequence rankings were not included because of data quality limitations. Economic consequences estimates are based on overall county data. Including them in the index is likely to result in biased estimation of hazard risk. The natural environment impact assessment is limited to the environmental resources identified through land cover dataset. Each natural hazard is associated with specific effects on the natural environment and therefore adoption of a common evaluation approach across all hazard types for environmental impacts is not appropriate. For floods, no quantitative assessment for environmental impacts was undertaken because of the data limitations. The landcover data categories do not allow for this analysis.

Seven counties including Grays Harbor, Lewis, Lincoln, Okanogan, Pacific, Skagit, and Wahkiakum are ranked high for flood risks, followed by Cowlitz, Franklin, Garfield, Grant, Jefferson, Mason, Snohomish, and Whatcom Counties that are ranked medium-high. Counties ranked medium for flooding risk include Adams, Chelan, Clallam, Columbia, King, Kittitas, Pierce, San Juan, Skamania, Thurston, Whitman, and Yakima. It is highlighted that the risk assessment is primarily based on the most recent flood maps available with the State of Washington. Not all maps have been updated in recent years and may under-represent the real flooding risk.

Flood Risk Index (WaSRI F) and Constituent Exposure Ranks for Each County

County	Area	Population	Vulnerable Population	Built Environment	Critical Infrastructure	State Facilities	First Responder Facilities	Flood Risk Index (WaSRI F)
Adams	MEDIUM-LOW	LOW	MEDIUM-HIGH	LOW	MEDIUM	MEDIUM-HIGH	MEDIUM-HIGH	MEDIUM
Asotin	LOW	LOW	LOW	LOW	LOW	HIGH	MEDIUM-HIGH	LOW
Benton	MEDIUM	MEDIUM-LOW	MEDIUM	MEDIUM-LOW	LOW	MEDIUM-LOW	LOW	LOW
Chelan	LOW	MEDIUM-HIGH	MEDIUM-HIGH	MEDIUM-HIGH	MEDIUM-HIGH	MEDIUM-LOW	MEDIUM	MEDIUM
Clallam	MEDIUM	MEDIUM-LOW	MEDIUM	MEDIUM-LOW	MEDIUM-HIGH	MEDIUM-HIGH	MEDIUM	MEDIUM
Clark	MEDIUM-HIGH	LOW	MEDIUM	LOW	MEDIUM	MEDIUM-LOW	MEDIUM-LOW	MEDIUM-LOW
Columbia	MEDIUM-LOW	MEDIUM-HIGH	LOW	MEDIUM-HIGH	MEDIUM-LOW	MEDIUM	HIGH	MEDIUM
Cowlitz	MEDIUM	MEDIUM-HIGH	HIGH	MEDIUM-HIGH	MEDIUM-HIGH	HIGH	LOW	MEDIUM-HIGH
Douglas	LOW	MEDIUM-LOW	MEDIUM-HIGH	MEDIUM-LOW	LOW	MEDIUM	LOW	LOW
Ferry	LOW	HIGH	LOW	HIGH	LOW	MEDIUM-HIGH	LOW	MEDIUM-LOW
Franklin	MEDIUM	MEDIUM	HIGH	MEDIUM	MEDIUM-HIGH	MEDIUM	MEDIUM	MEDIUM-HIGH
Garfield	LOW	HIGH	LOW	HIGH	MEDIUM-LOW	HIGH	HIGH	MEDIUM-HIGH
Grant	MEDIUM-HIGH	MEDIUM	HIGH	MEDIUM	MEDIUM	MEDIUM	HIGH	MEDIUM-HIGH
Grays Harbor	MEDIUM-HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	MEDIUM-HIGH	HIGH
Island	HIGH	MEDIUM-LOW	LOW	MEDIUM-LOW	LOW	LOW	HIGH	MEDIUM-LOW
Jefferson	HIGH	MEDIUM-HIGH	LOW	MEDIUM-HIGH	LOW	MEDIUM-HIGH	MEDIUM-HIGH	MEDIUM-HIGH

Flood Risk Index (WaSRI F) and Constituent Exposure Ranks for Each County

County	Area	Population	Vulnerable Population	Built Environment	Critical Infrastructure	State Facilities	First Responder Facilities	Flood Risk Index (WaSRI F)
King	MEDIUM	MEDIUM-LOW	MEDIUM-HIGH	LOW	MEDIUM-LOW	MEDIUM-LOW	LOW	MEDIUM
Kitsap	HIGH	LOW	LOW	LOW	MEDIUM-LOW	LOW	MEDIUM-LOW	LOW
Kittitas	MEDIUM-LOW	MEDIUM-HIGH	LOW	MEDIUM-HIGH	MEDIUM	MEDIUM	MEDIUM-LOW	MEDIUM
Klickitat	MEDIUM-LOW	MEDIUM	LOW	MEDIUM	MEDIUM-LOW	MEDIUM-HIGH	MEDIUM	MEDIUM-LOW
Lewis	MEDIUM-HIGH	HIGH	MEDIUM-HIGH	HIGH	HIGH	HIGH	MEDIUM	HIGH
Lincoln	MEDIUM-LOW	HIGH	LOW	HIGH	MEDIUM-HIGH	HIGH	HIGH	HIGH
Mason	HIGH	MEDIUM	MEDIUM-HIGH	MEDIUM	HIGH	LOW	MEDIUM-HIGH	MEDIUM-HIGH
Okanogan	LOW	HIGH	HIGH	HIGH	MEDIUM	HIGH	MEDIUM	HIGH
Pacific	MEDIUM-HIGH	MEDIUM	HIGH	MEDIUM	HIGH	MEDIUM-HIGH	MEDIUM-HIGH	HIGH
Pend Oreille	MEDIUM-LOW	LOW	LOW	LOW	LOW	LOW	MEDIUM-LOW	LOW
Pierce	MEDIUM-HIGH	MEDIUM-LOW	MEDIUM	MEDIUM-LOW	MEDIUM	MEDIUM	LOW	MEDIUM
San Juan	HIGH	MEDIUM-LOW	LOW	MEDIUM-LOW	MEDIUM-LOW	MEDIUM-LOW	HIGH	MEDIUM
Skagit	HIGH	HIGH	HIGH	HIGH	HIGH	MEDIUM-HIGH	MEDIUM-HIGH	HIGH
Skamania	LOW	MEDIUM-LOW	LOW	MEDIUM-LOW	MEDIUM-HIGH	HIGH	HIGH	MEDIUM
Snohomish	MEDIUM-HIGH	MEDIUM	MEDIUM-HIGH	MEDIUM	HIGH	MEDIUM-LOW	MEDIUM-LOW	MEDIUM-HIGH
Spokane	MEDIUM-LOW	LOW	MEDIUM	LOW	LOW	MEDIUM-LOW	MEDIUM-LOW	LOW
Stevens	MEDIUM-LOW	LOW	MEDIUM	LOW	MEDIUM-LOW	MEDIUM-HIGH	LOW	LOW

Flood Risk Index (WaSRI F) and Constituent Exposure Ranks for Each County

County	Area	Population	Vulnerable Population	Built Environment	Critical Infrastructure	State Facilities	First Responder Facilities	Flood Risk Index (WaSRI F)
Thurston	HIGH	MEDIUM-LOW	MEDIUM	MEDIUM-LOW	MEDIUM	LOW	LOW	MEDIUM
Wahkiakum	HIGH	HIGH	LOW	HIGH	HIGH	LOW	HIGH	HIGH
Walla Walla	MEDIUM	MEDIUM-HIGH	LOW	MEDIUM-HIGH	MEDIUM-LOW	LOW	MEDIUM	MEDIUM-LOW
Whatcom	MEDIUM-HIGH	MEDIUM-HIGH	MEDIUM-LOW	MEDIUM-HIGH	HIGH	MEDIUM-LOW	MEDIUM	MEDIUM-HIGH
Whitman	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM-HIGH	MEDIUM
Yakima	LOW	MEDIUM-HIGH	HIGH	MEDIUM-HIGH	MEDIUM-HIGH	LOW	MEDIUM-LOW	MEDIUM

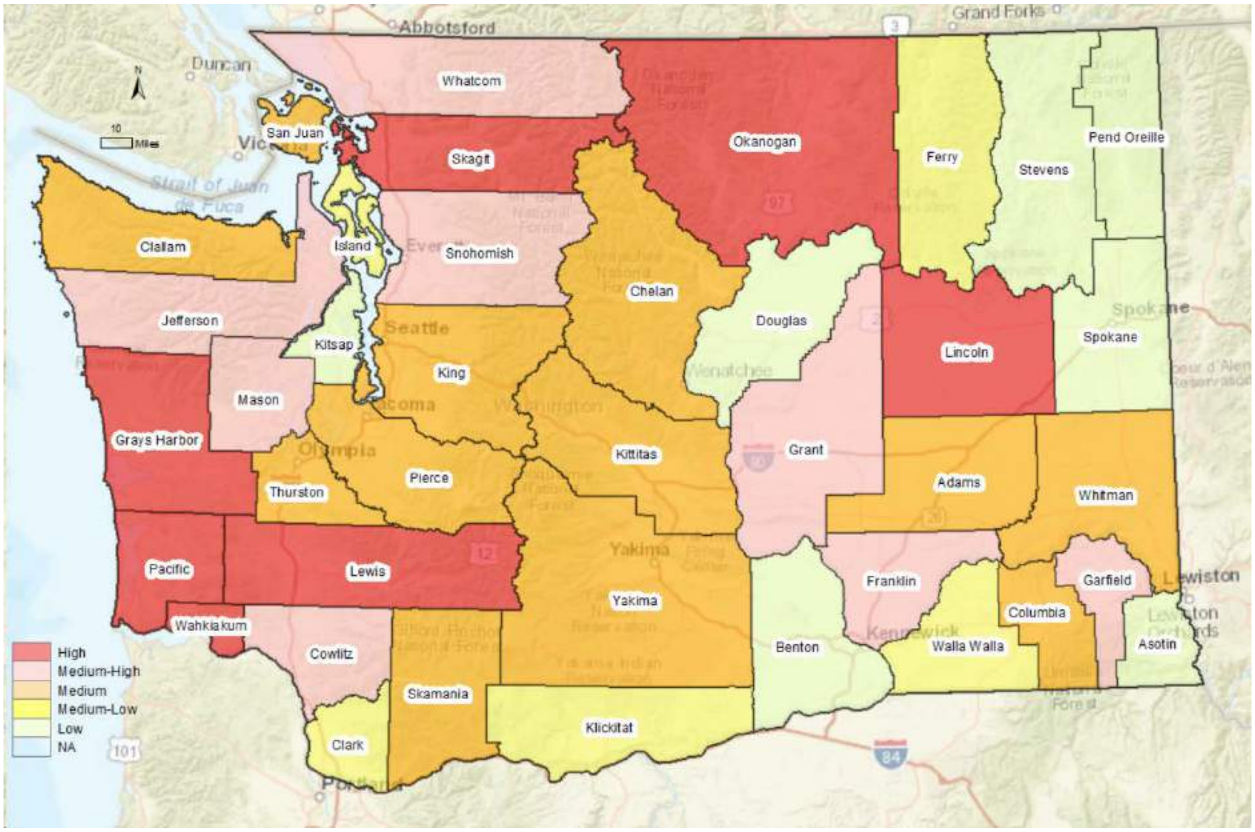


FIGURE F 7: FLOOD RISK INDEX (WASRI-F)

Economic Consequences

The economic activity data was derived from National Association of Counties. This dataset provides the county level estimates of Gross Domestic Product (GDP) for 2016. Flooding events are likely to have significant impact on the state's economy. The counties ranked medium or higher on the flood risk index account for 83 percent of the state's GDP. Seven counties ranked high for flood risk contribute less than 3 percent to the state GDP. Eight counties ranked medium-high, including Snohomish County, contribute another 14 percent to the state GDP. King County, by far the highest contributor to the state GDP is ranked medium for flood risks. The next two top contributors to state GDP, Pierce and Snohomish Counties are ranked medium and medium-high on the flood risk index.

Climate change is increasing flood risk and accordingly presenting challenges to our economy. Lack water discharges and reduced flooding during increasingly hotter summer months may have a greater impact than that caused directly by flooding. These reductions in summer flows will stress our forests resulting in an increased risk of wild fires which will in turn increase flood risks. Reduced summer flows are and will continue to force the state's agricultural sector to adapt to reduced water availability.

This assessment does not include impacts from flooded corridor segments.

Drought Risk (WaSRI D) and County GDP 2016

County	Drought Risk Index (WaSRI D)	GDP 2016 (in Mil.)
Adams	MEDIUM	$746.07
Asotin	LOW	$618.43
Benton	LOW	$10,627.85
Chelan	MEDIUM	$4,363.01
Clallam	MEDIUM	$2,573.06
Clark	MEDIUM-LOW	$18,682.64
Columbia	MEDIUM	$144.20
Cowlitz	MEDIUM-HIGH	$4,474.88
Douglas	LOW	$1,037.39
Ferry	MEDIUM-LOW	$198.13
Franklin	MEDIUM-HIGH	$3,356.16
Garfield	MEDIUM-HIGH	$97.44
Grant	MEDIUM-HIGH	$3,803.65
Grays Harbor	HIGH	$2,237.44
Island	MEDIUM-LOW	$2,796.80
Jefferson	MEDIUM-HIGH	$867.23
King	LOW	$230,344.61
Kitsap	LOW	$12,082.18
Kittitas	MEDIUM	$1,566.21
Klickitat	MEDIUM-LOW	$1,004.05
Lewis	HIGH	$2,573.06
Lincoln	HIGH	$347.25
Mason	MEDIUM-HIGH	$1,566.21
Okanogan	HIGH	$1,678.08

Drought Risk (WaSRI D) and County GDP 2016		
County	Drought Risk Index (WaSRI D)	GDP 2016 (in Mil.)
Pacific	HIGH	$637.45
Pend Oreille	LOW	$354.63
Pierce	MEDIUM-LOW	$41,280.80
San Juan	MEDIUM	$602.88
Skagit	HIGH	$5,705.48
Skamania	MEDIUM	$218.04
Snohomish	MEDIUM-HIGH	$39,378.97
Spokane	LOW	$24,723.73
Stevens	LOW	$1,111.56
Thurston	MEDIUM-LOW	$12,865.29
Wahkiakum	HIGH	$93.41
Walla Walla	MEDIUM-LOW	$2,908.67
Whatcom	MEDIUM-HIGH	$10,068.49
Whitman	MEDIUM	$2,237.44
Yakima	MEDIUM	$10,404.10

Risk to Environment

Direct environmental impacts of flooding are likely to be limited. Flooding serves an important ecological function of floodplain enrichment. Floods are critical to ensuring continued biological productivity and diversity in the floodplain. Most damages occur from increased urban growth and encroachment into the floodplain areas. Most existing species in the flood zone are well adapted to flooding events in their habitat areas.

The state's changing climate is stressing these floods related environmental processes. Of concern are increased winter flows, velocity and accompanying increases in sediment loading. Greater channel erosion and aggradation is expected. This may stress existing salmon runs and riparian existing habitat. However, the lack of summer flows and related flooding may cause more change as our Cascadia drainage becomes increasingly rain dominant and summer flows diminish.

Flooding often washes man-made pollutants into water courses, stressing the riverine habitat. Flood waters often also carry debris such as trees and stones, and at times even parts of washed away structures. This can have negative impacts on the riverine habitats.

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Hazardous Materials Hazard Profile

Risk Summary

Frequency – Hazardous material releases happen each year in Washington state.

People – Though hazardous material releases can adversely affect or kill people, the likelihood that a hazardous material release would kill more than 1,000 people to meet the minimum threshold for this category is highly unlikely.

Economy –Recovery from a hazardous material release is not likely to cost 1 percent of the state's Gross Domestic Product (GDP) to meet this category's minimum threshold.

Environment – While the environment and species that inhabit the areas in and around a hazardous material release can be adversely affected in an event, the likelihood that 10 percent of a single species or habitat will be lost due to a hazardous material release is highly unlikely.

Property – Recovery from a hazardous material release is not likely to cost more than $100 million to meet this category's minimum threshold.

State Operations and Facilities – Not assessed for this hazard.

First Responders – Hazardous materials incidents require advanced training and personal protective equipment. Failures of equipment or accidental exposure can cause injury, death or permanent disability.

Public Confidence – Hazardous materials, especially hazardous material transport, is a serious political issue in Washington state. Already controversial, an incident on a pipeline or oil train could have cascading impacts on public confidence in industry and government regulation.

The Hazard – Hazardous materials incidents include the unwanted, unplanned or deliberate release or escape of explosive, flammable, combustible, corrosive, reactive, poisonous, toxic, or that may cause or create a potential risk to public health, safety or the environment.

Previous Occurrences – Washington has a varied history of hazardous materials incidents and while some appear to be on the downward trend (such as drug lab incidents), others remain fairly constant but vary by location and amount (oil and chemical spills or releases, etc.).

Probability of Future Events – Determining the probability of future hazardous materials incidents is difficult because so many factors can contribute and there are so many different types of incidents.

Jurisdictions at Greatest Risk – Hazardous materials incidents have impacted every county in the state and are dependent upon a variety of conditions. Western Washington counties are potentially more at risk due to dense industrial and populated areas and major transportation routes surrounding the fragile ecosystems of the Puget Sound and coastal waterways. Some Eastern counties are increasingly at risk with growth in population, industry and transportation. For the purpose of this profile, analysis will not be conducted to determine the jurisdiction of greatest risk.

The following hazardous materials categories are considered for this profile:

- Spills either at fixed facilities or on transportation routes which include water, land and pipeline;
- Methamphetamine labs; and
- Washington cleanup sites for leaking underground storage tanks, brownfields and superfund sites.

Risk Profile

Hazardous materials are defined as such because of their chemical, physical or biological nature which can pose a potential risk to human health, property or the environment when released. A release may occur by spilling, leaking, emitting toxic vapors or any other process that enables the material to escape its container, enter the environment and create a potential hazard. Potential sources of hazardous material releases include, but are not limited to: superfund sites, storage facilities, residences, manufacturers, transportation carriers, hospitals/medical facilities, veterinary hospitals/clinics and brownfield sites. The hazard can be explosive, flammable, combustible, corrosive, reactive, poisonous, toxic or radioactive, and can exhibit qualities of a biological agent. There are also naturally occurring hazardous materials releases. These naturally occurring hazardous material releases may produce the same potential risk to human health as the manufactured chemicals or agents.

In addition to the standard definition of hazardous materials, there are other agents which also fall into this category. Etiologic agents are those microorganisms and microbial toxins that cause disease in humans and include bacteria, bacterial toxins, viruses, fungi, rickettsia, protozoans and parasites. These disease-causing microorganisms may also be referred to as infectious agents. Arthropods and other organisms that transmit pathogens to animals (including humans) are called vectors. Etiologic agents, vectors and materials containing etiologic agents are recognized as hazardous materials.

Hazardous materials incidents can occur naturally and during the manufacture, transportation, storage and use of hazardous materials. These incidents can occur as a result of human error, natural hazards, deliberate deed or a breakdown in equipment or monitoring systems. The impact depends upon the quantity and physical properties of the hazardous material, environmental and weather factors at the point of release, the type of release and its proximity to human and wildlife populations and valuable ecosystems.

In 1986 Congress enacted the Emergency Planning and Community Right to Know Act (EPCRA) as part of the Superfund Amendments and Reauthorization Act (SARA) due to public concern regarding the environmental and safety hazards posed by the storage and handling of toxic chemicals. This act, known as SARA Title III, established requirements for federal, state, tribal and local governments as well as industry regarding emergency response planning and the public’s right to know about hazardous chemicals stored and released in their community. These provisions helped increase the public's knowledge and access to information on chemicals at individual facilities, their uses and releases into the environment.

In 1987, Washington adopted the Federal SARA Title III regulations in Chapter 118-40 of the Washington Administrative Code and established the Washington State Emergency Response Commission (SERC) to oversee implementation of requirements imposed by SARA Title III, including the creation of planning districts, designation of the Local Emergency Planning Committees (LEPC), and the development of a statewide master plan for hazardous materials incident response. The Washington SERC is comprised of a broad-based membership including representatives from private industry, state, tribal and local governments. In addition, the Washington State Patrol, the Washington State Military Department's Emergency Management Division and the Department of Ecology have specific responsibilities under the state regulation. The LEPC's representation consists of state and local elected officials, law enforcement, emergency management, firefighting, health professionals, hospital, transportation, environmental, media, community groups and owners and operators of facilities subject to the requirements of Section 302(b) of EPCRA. LEPCs are required to develop a local hazardous materials emergency plan for their district and to collect EPCRA information submitted by industry. Each local committee shall establish procedures for receiving and processing requests from the general public for information under Section 324 (including Tier II information under Section 312) EPCRA. Such procedures shall include the designation of an official to serve as committee coordinator for all information requests.

According to the Department of Ecology and Washington Emergency Management Division, in 2018 Washington state has 42 LEPCs, one for each of Washington's 39 counties as well as for the Emergency Services Coordinating Agency, the Southwest Snohomish Emergency Services Coordinating Agency and the Fort Lewis military installation/reservation.

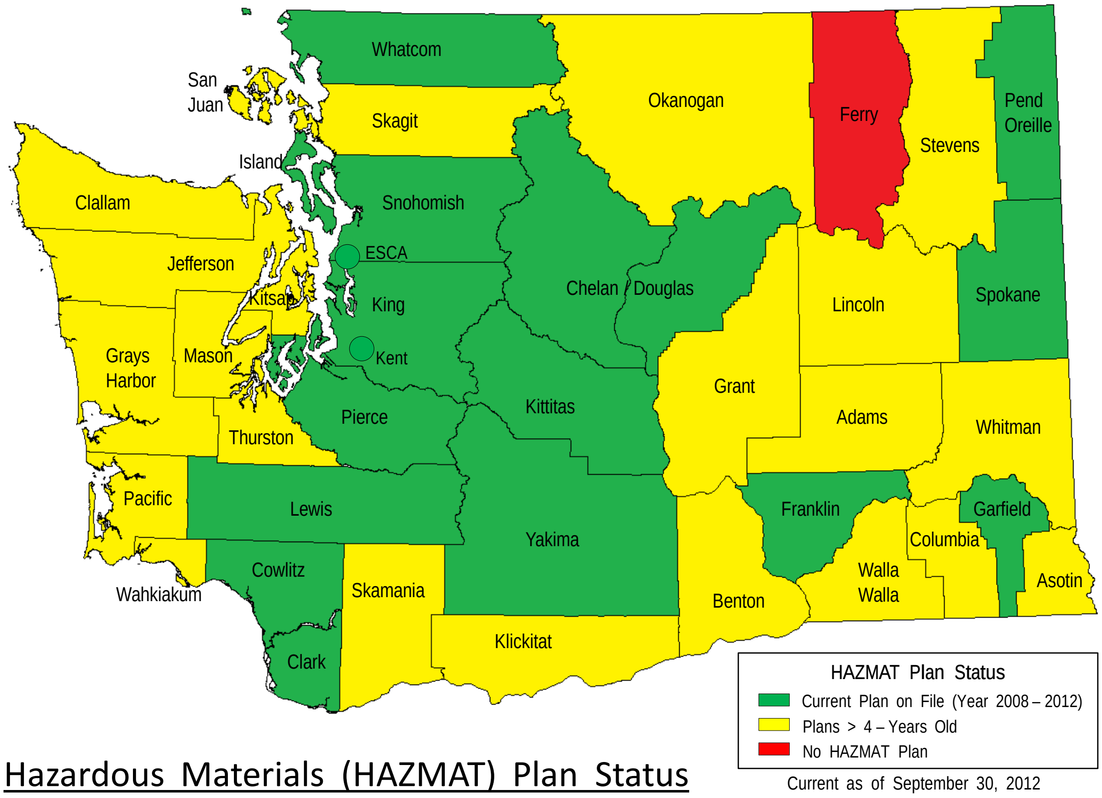


FIGURE HM1: COUNTY HAZMAT PLANNING STATUS

The Washington SERC requires that all facilities or businesses that have reportable quantities of certain chemicals must complete a Tier Two – Emergency and Hazardous Chemical Inventory report annually for each hazardous or extremely hazardous substance present in excess of its threshold at any one time. The Washington Department of Ecology receives all EPCRA reports and manages EPCRA data on behalf of the Washington SERC. Most EPCRA reports must also be submitted to the LEPC, the local fire department or, when appropriate, to tribal nations or tribal emergency response commissions, their designated LEPC's and fire departments.

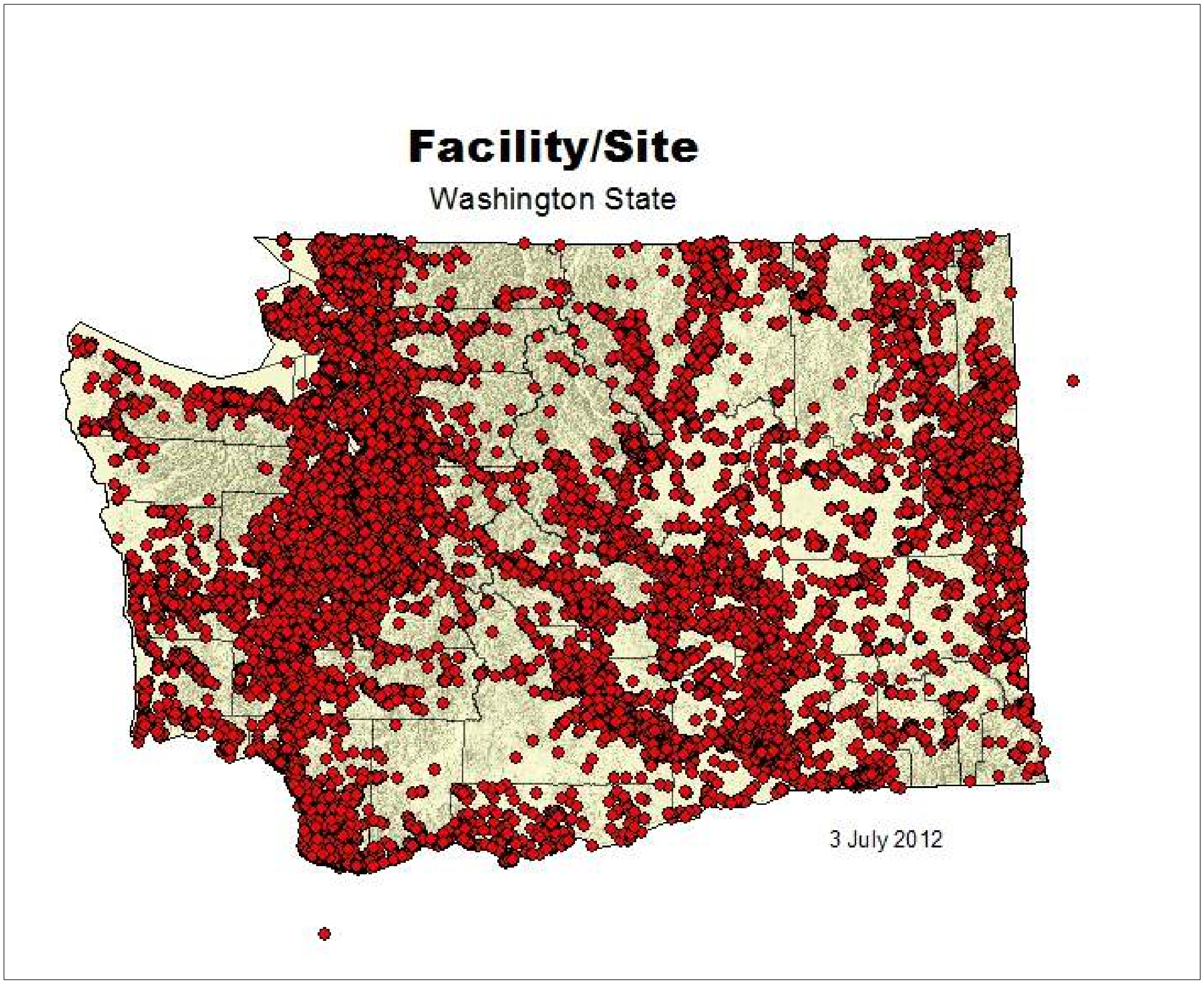


FIGURE HM2: LOCATIONS OF FACILITIES AND SITES WITH HAZARDOUS CHEMICALS

To help citizens, government and industry better prepare for emergency response to chemical releases, the Washington State Emergency Response Commission (SERC) assembles and disseminates Tier Two data for facilities covered under the federal Community Right-to-Know laws. Reporting thresholds are: 10,000 pounds of a *hazardous substance* at any one time, and 500 pounds or less of an *extremely hazardous substance*. The graphic above indicates the total number of Tier Two reporting facilities and reportable substances by county for 2012 for hazardous substances.

Specific Washington laws relating to hazardous materials include: RCW 90.56 – *Oil and Hazardous Substance Spill Prevention and Response;* RCW 88.46 – *Vessel Oil Spill Prevention and Response;* RCW 90.48 – *Water Pollution Control;* RCW 88.40 – *Transport of Petroleum Products – Financial Responsibility;* RCW 70.105 – *Hazardous Waste Management;* RCW 70.105D – *Hazardous Waste Cleanup – Model Toxics Control Act; Chapter 118-40 WAC Hazardous Chemical Emergency Response Planning and Community Right-to-know reporting.*

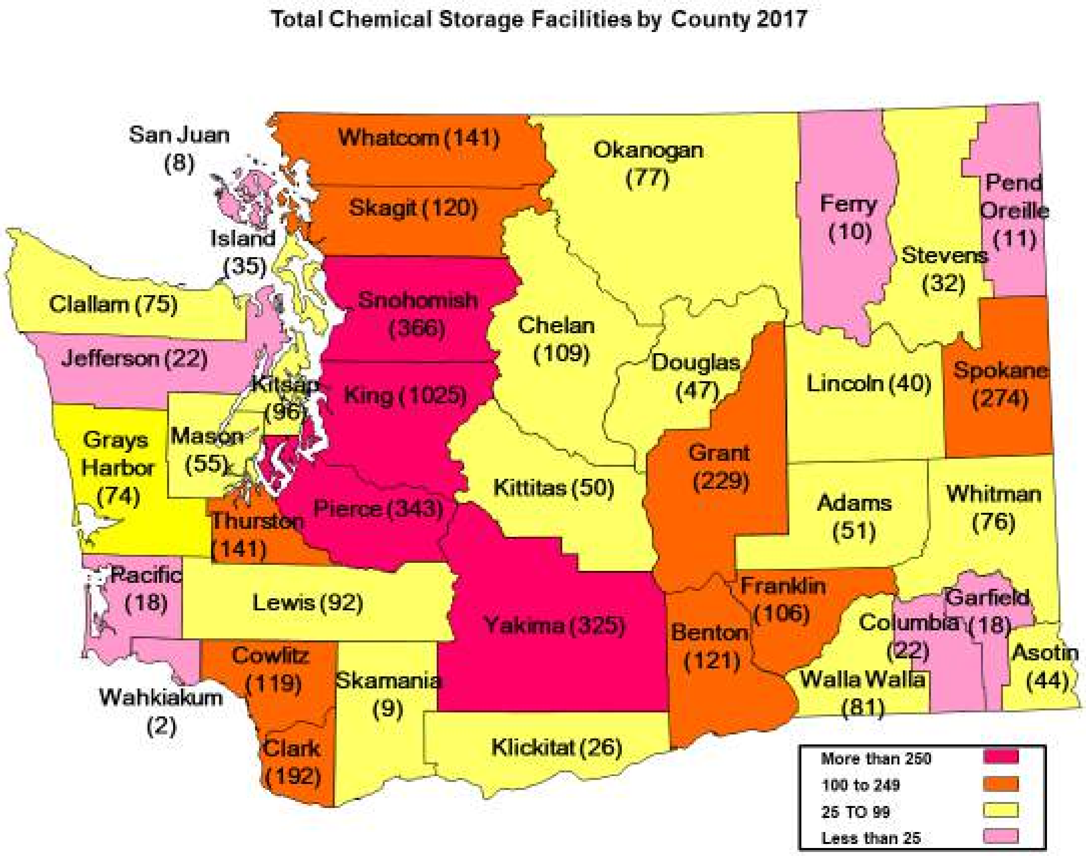


FIGURE HM3: COUNTY HAZMAT FACILITIES AND CHEMICALS

On January 8, 2018, the U.S. Environmental Protection Agency (EPA) released its 2016 Toxics Release Inventory (TRI) report. The TRI national analysis is an annual report that provides EPA's analysis and interpretation of the most recent TRI data. It includes information about toxic chemical releases to the environment from facilities that report to the TRI program. It also includes information about how toxic chemicals are managed through recycling, treatment and energy recovery, and how facilities are working to reduce the amount of toxic chemicals generated and released. The 2016 report includes geo-specific analyses for urban communities (Seattle-Bellevue-Tacoma metropolitan area), large aquatic ecosystems (Puget Sound Georgia Basin and Columbia River Basin), Indian Country and Alaska Native Villages (Tulalip Tribes), and state fact sheets. See https://www.epa.gov/newsreleases/epa-publishes-annual-toxics-release-inventory-report-and-analysis

An excerpt from the Urban Communities Analysis: The Seattle-Tacoma-Bellevue, WA metropolitan statistical area in the Puget Sound region of Washington is composed of King, Snohomish and Pierce counties. With a population of 4.7 million, it is the 13th largest U.S. metropolitan statistical area. Other cities in the Seattle metropolitan area include Tacoma, Bellevue, Everett, Kent, Renton and Auburn.

Economic activity within the metropolitan area includes the manufacturing of aircraft, ships, biomedical products, forest products, seafood products, aluminum, steel, textiles, clothing, electronics, and metal and glass products. In addition, the Port of Seattle is a major port city for trans-Pacific and European trade and is the fifth largest container port in the United States.

Air releases accounted for 83 percent of total on-site disposal or other releases in the Seattle metropolitan area during 2011. The paper products sector reported 55 percent of the total air releases, mainly composed of hydrochloric acid and methanol. This sector also accounted for more than 99 percent of chemicals discharged to surface water, mainly nitrate compounds and methanol. One pulp and paper mill accounted for 44 percent of all air releases and 59 percent of all surface water discharges reported by facilities in the Seattle metropolitan area.

To help emergency responders become aware of the possible chemicals they may encounter at the locations of an incident, the U.S. Department of Transportation has established a hazardous materials placard system. Railroad cars and trucks carrying chemicals or hazardous wastes must display a diamond-shaped placard which includes a material identification number, a hazard class number and symbol, which identifies the material as a flammable liquid or solid, non-flammable or flammable gas, explosive, corrosive, toxic, oxidizer or organic peroxide, environmentally hazardous or radioactive material.

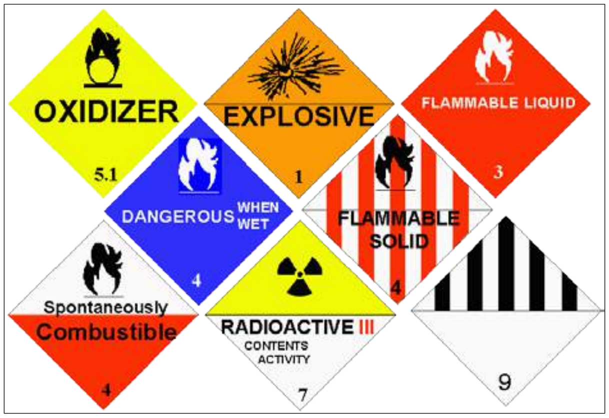


FIGURE HM4: U.S. DEPARTMENT OF TRANSPORTATION PLACARDS

The Washington State Emergency Management Alert and Warning Center monitors various state and national alert systems besides tracking emergency incidents like hazardous materials (hazmat) spills. Hazmat incidents accounts for more than half of the 2011 statistics below.

Reported Incidents 2017

Hazmat	2581
Search and Rescue	999
Other	947
Fire	353
Total	4982

Spills

In Washington state, more than 20 billion gallons of oil and hazardous chemicals are transported by ship, barge, pipeline, rail and road each year. Equipment failure and human error in these situations can lead to oil and chemical spills that threaten public health and wildlife, contaminate the environment and ultimately damage the state's economy and quality of life.

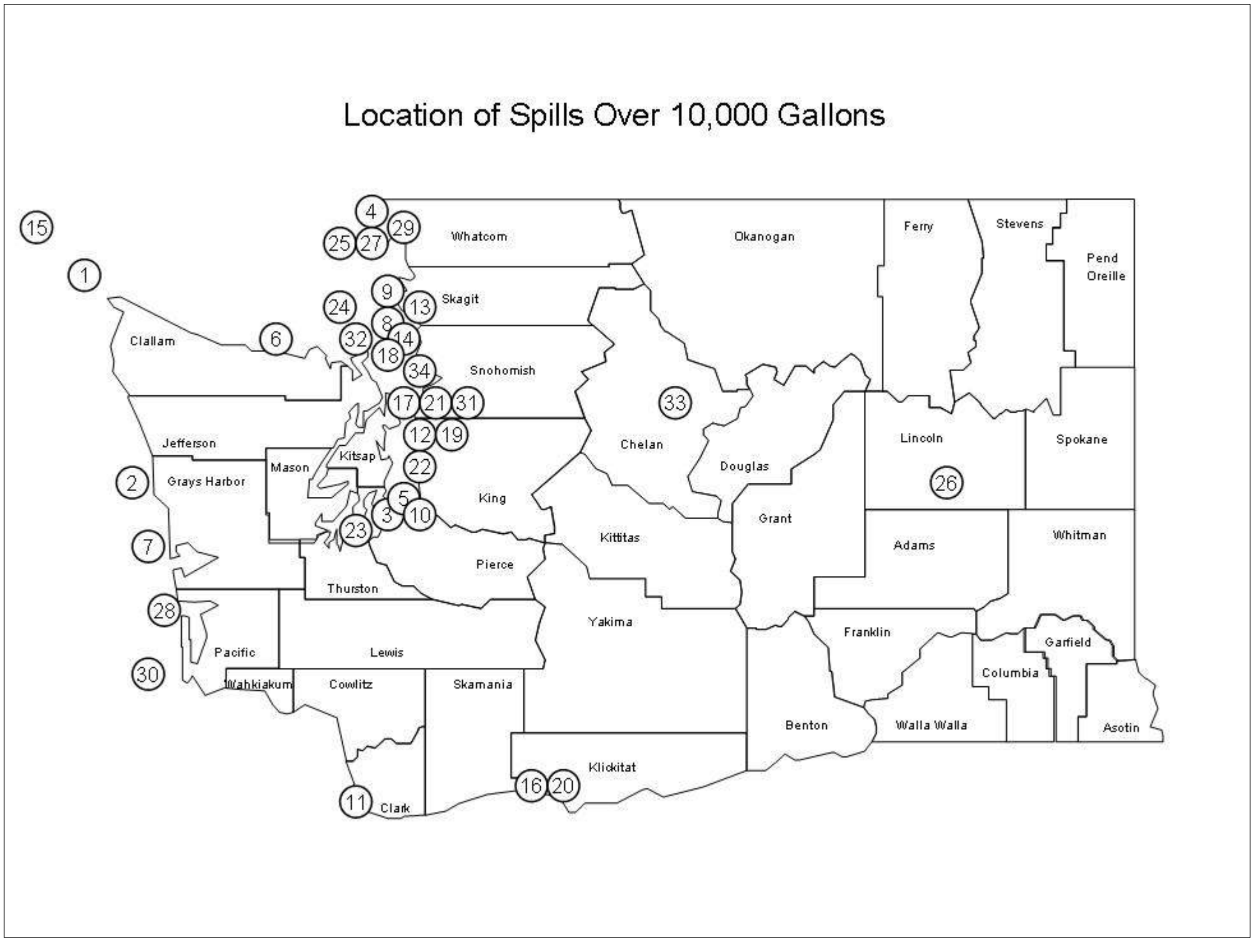


FIGURE HM5: OIL SPILLS IN WASHINGTON STATE A HISTORICAL ANALYSIS

The Department of Ecology's Spill Prevention, Preparedness and Response Program works to protect Washington's environment, public health and safety through a variety of methods aimed first at preventing, but also by responding to spills when they do occur. Spill prevention actions include establishing a stricter oil transfer program for commercial maritime operations, increasing refinery, pipeline and vessel inspections, and stationing a government-funded rescue tug at Neah Bay to aid disabled vessels through emergency towing and salvage services. Ecology's spill response capability is maintained 24-hours-a-day, 7-days-a-week throughout the state. Ecology continues to receive more than 4,000 spill reports annually.

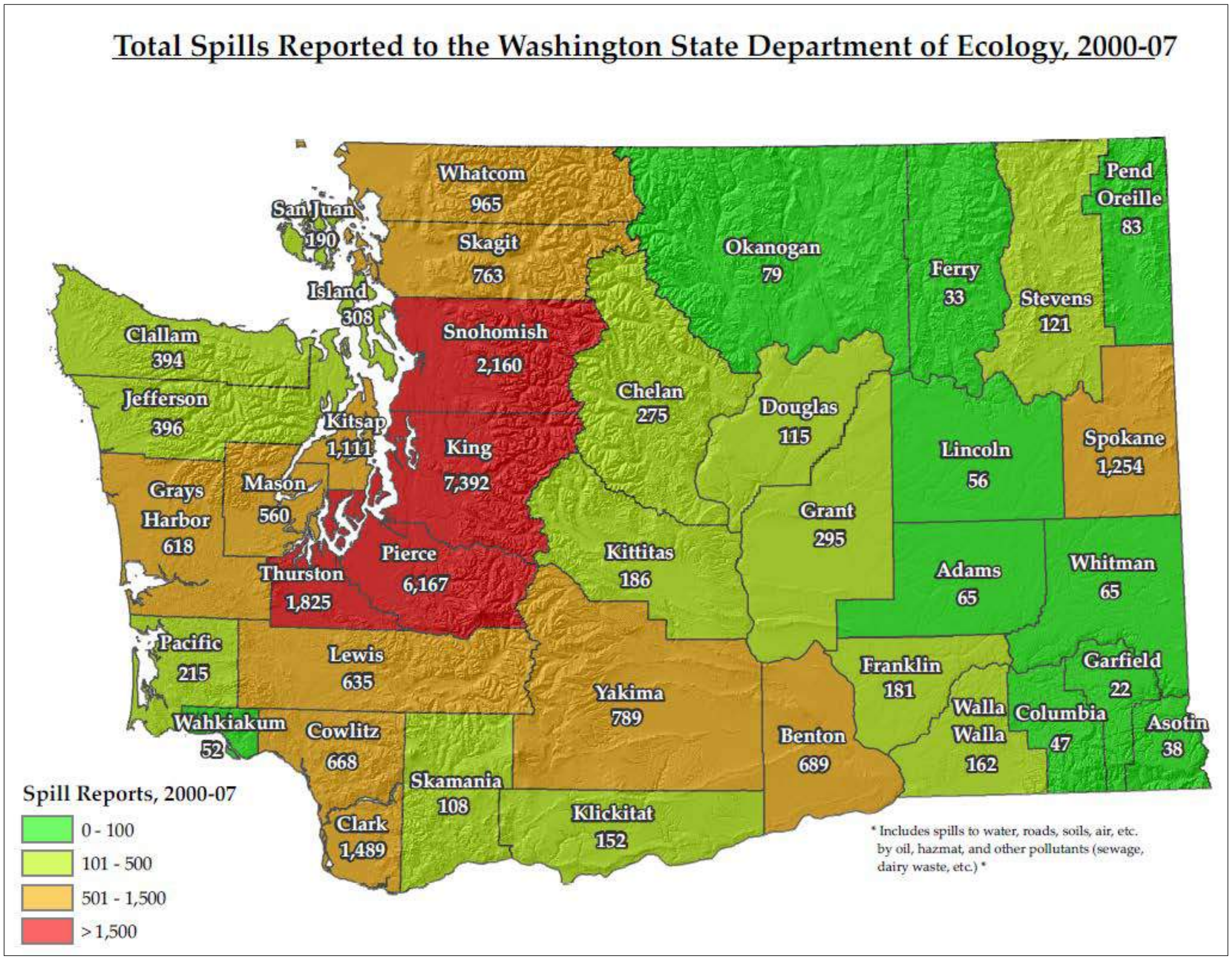


FIGURE HM6: TOTAL SPILLS REPORTED

Clandestine Methamphetamine Labs and Dump Site Cleanup Activity

Illegal drug labs encountered by state and local agencies increased dramatically from 38 in 1990 to 1,890 in 2001 at its peak, to 92 in 2010. Ecology is responsible for handling and disposing of hazardous substances found at illegal drug lab sites. Nearly all of Washington's clandestine drug labs manufacture methamphetamine – also called *meth*, *crystal*, *crank* or *speed*. Law enforcement intelligence indicates the recent decline may correspond with inexpensive drugs manufactured in Mexico and entering the United States.

The Commencement Bay Nearshore/Tideflats Superfund site is located in the City of Tacoma and the Town of Ruston at the southern end of Puget Sound in Washington. It encompasses an active commercial seaport and includes 12 square miles of shallow water, shoreline, and adjacent land, most of which is highly developed and industrialized. The United States Environmental Protection

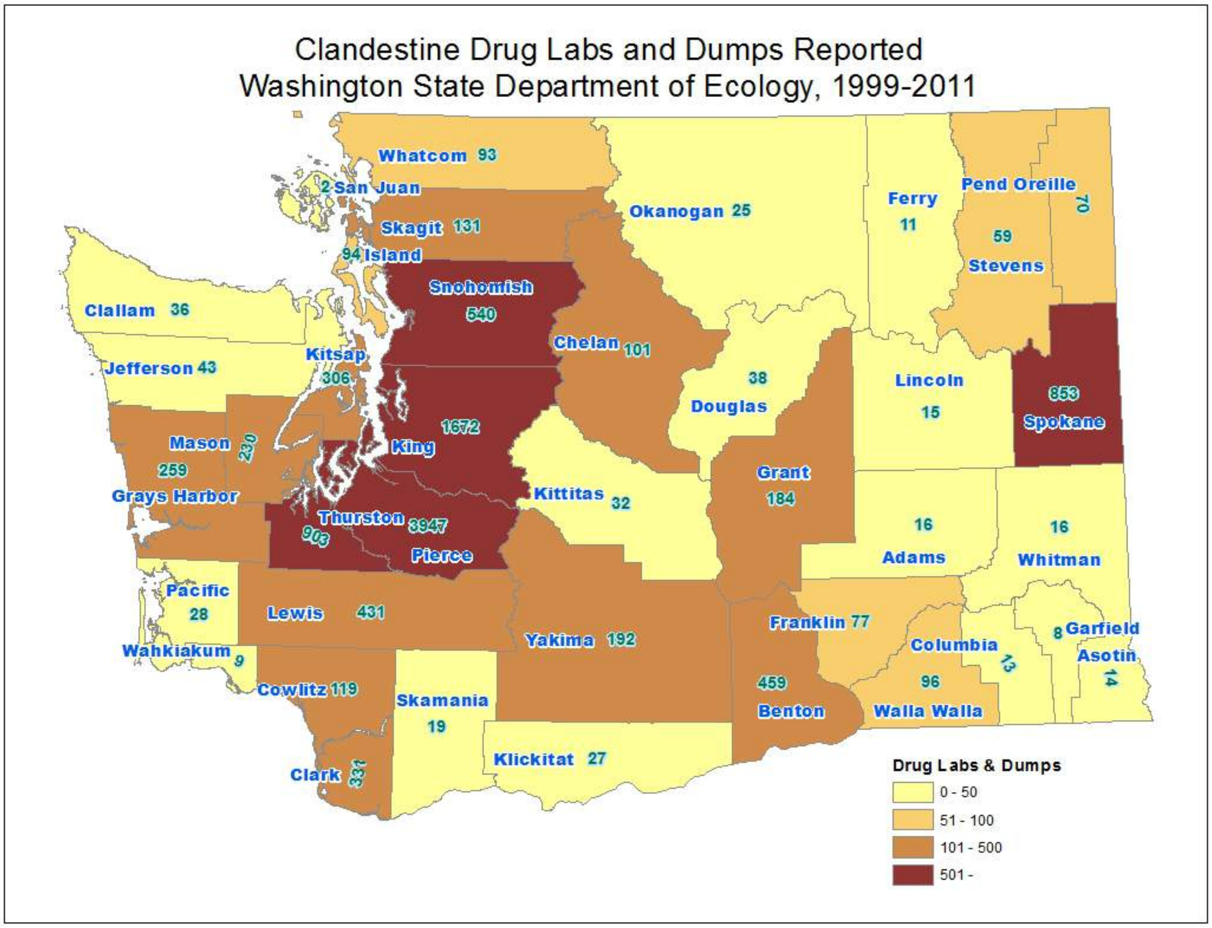


FIGURE HM7: WASHINGTON CLEANUP SITES

Agency (EPA) placed the site on the Superfund National Priorities List in 1983 due to widespread contamination of the water, sediments and upland areas.

The U.S. Department of Energy Hanford Site, located near the City of Richland, Washington, was established to produce nuclear materials for national defense. The Hanford Site was placed on EPA's Superfund National Priorities List of contaminated sites in 1989.

The Lower Duwamish Waterway Superfund Site is a 5.5 mile stretch of the Duwamish River that flows into Elliott Bay in Seattle, Washington. The waterway is flanked by industrial corridors, as well as the South Park and Georgetown neighborhoods. The site was added to EPA's Superfund National Priorities List in 2001.

Washington State Cleanup Sites	
BAINBRIDGE ISLAND	WYCKOFF CO./EAGLE HARBOR
BELLINGHAM	OESER CO.
BENTON COUNTY	HANFORD 100-AREA (USDOE)
BENTON COUNTY	HANFORD 1100-AREA (USDOE)
BENTON COUNTY	HANFORD 200-AREA (USDOE)
BENTON COUNTY	HANFORD 300-AREA (USDOE)
BREMERTON	BANGOR ORDNANCE DISPOSAL (USNAVY)
BREMERTON	BREMERTON GASWORKS
BREMERTON	PUGET SOUND NAVAL SHIPYARD COMPLEX
BRUSH PRAIRIE	TOFTDAHL DRUMS
CENTRALIA	CENTRALIA MUNICIPAL LANDFILL
CHEHALIS	AMERICAN CROSSARM & CONDUIT CO.
CHEHALIS	HAMILTON/LABREE ROADS GW CONTAMINATION
EVERSON	NORTHWEST TRANSFORMER
EVERSON	NORTHWEST TRANSFORMER (SOUTH HARKNESS STREET)
FREEMAN	GRAIN HANDLING FACILITY AT FREEMAN
INDIAN ISLAND	PORT HADLOCK DETACHMENT (USNAVY)
KENT	MIDWAY LANDFILL
KENT	SEATTLE MUNICIPAL LANDFILL (KENT HIGHLANDS)
KENT	WESTERN PROCESSING CO., INC.
KEYPORT	NAVAL UNDERSEA WARFARE ENGINEERING STATION (4 WASTE AREAS)
KITSAP COUNTY	JACKSON PARK HOUSING COMPLEX (USNAVY)
LAKEWOOD	LAKEWOOD
LOOMIS	SILVER MOUNTAIN MINE

Washington State Cleanup Sites	
MANCHESTER	OLD NAVY DUMP/MANCHESTER LABORATORY (USEPA/NOAA)
MAPLE VALLEY	QUEEN CITY FARMS
MARYSVILLE	BOEING COMPANY TULALIP TEST SITE
MARYSVILLE	TULALIP LANDFILL
MEAD	KAISER ALUMINUM (MEAD WORKS)
MICA	MICA LANDFILL
MOSES LAKE	MOSES LAKE WELLFIELD CONTAMINATION
NEAH BAY	MAKAH RESERVATION WARMHOUSE BEACH DUMP
NORTH BONNEVILLE	HAMILTON ISLAND LANDFILL (USA/COE)
PASCO	PASCO SANITARY LANDFILL
PIERCE COUNTY	HIDDEN VALLEY LANDFILL (THUN FIELD)
RENTON	PACIFIC CAR & FOUNDRY CO.
RENTON	QUENDALL TERMINALS
SEATTLE	HARBOR ISLAND (LEAD)
SEATTLE	LOCKHEED WEST SEATTLE
SEATTLE	LOWER DUWAMISH WATERWAY
SEATTLE	PACIFIC SOUND RESOURCES
SILVERDALE	BANGOR NAVAL SUBMARINE BASE
SPOKANE	COLBERT LANDFILL
SPOKANE	FAIRCHILD AIR FORCE BASE (4 WASTE AREAS)
SPOKANE	GENERAL ELECTRIC CO. (SPOKANE APPARATUS SERVICE SHOP)
SPOKANE	NORTH MARKET STREET
SPOKANE	NORTHSIDE LANDFILL
SPOKANE	OLD INLAND PIT
SPOKANE	SPOKANE JUNKYARD/ASSOCIATED PROPERTIES

Washington State Cleanup Sites	
SPOKANE COUNTY	GREENACRES LANDFILL
TACOMA	AMERICAN LAKE GARDENS/MCCHORD AFB
TACOMA	COMMENCEMENT BAY, NEAR SHORE/TIDE FLATS
TACOMA	COMMENCEMENT BAY, SOUTH TACOMA CHANNEL
TACOMA	FORT LEWIS (LANDFILL NO. 5)
TACOMA	MCCHORD AIR FORCE BASE (WASH RACK/TREATMENT AREA)
TILLICUM	FORT LEWIS LOGISTICS CENTER
TUMWATER	PALERMO WELL FIELD GROUND WATER CONTAMINATION
VANCOUVER	ALCOA (VANCOUVER SMELTER)
VANCOUVER	BONNEVILLE POWER ADMINISTRATION ROSS COMPLEX (USDOE)
VANCOUVER	BOOMSNUB/AIRCO
VANCOUVER	FRONTIER HARD CHROME, INC.
VANCOUVER	VANCOUVER WATER STATION #1 CONTAMINATION
VANCOUVER	VANCOUVER WATER STATION #4 CONTAMINATION
WELLPINIT	MIDNITE MINE
WHIDBEY ISLAND	NAVAL AIR STATION, WHIDBEY ISLAND (AULT FIELD)
WHIDBEY ISLAND	NAVAL AIR STATION, WHIDBEY ISLAND (SEAPLANE BASE)
YAKIMA	FMC CORP. (YAKIMA)
YAKIMA	PESTICIDE LAB (YAKIMA)
YAKIMA	YAKIMA PLATING CO.

Source: US Environmental Protection Agency https://www.epa.gov/superfund/search-superfund-sites-where-you-live

Jurisdictions Most Threatened and Vulnerable to Hazardous Materials Hazards

Although Washington has a varied history of hazardous materials incidents including the unwanted, unplanned or deliberate release or escape of explosive, flammable, combustible, corrosive, reactive, poisonous, toxic or radioactive substances that may cause or create a potential risk to public health, safety or the environment, it is nevertheless very hard to predict. Determining future hazardous materials incidents is difficult because so many factors can contribute and there are so many different types of incidents. Nonetheless, hazardous materials incidents have impacted every county in the state.

Western Washington counties are more at risk due to dense industrial and populated areas and major transportation routes surrounding the fragile ecosystems of the Puget Sound and coastal waterways. There are three Superfund sites, two on the West side – the Commencement Bay Nearshore/Tideflats and the Lower Duwamish Waterway Superfund sites – and on the east side, Hanford. Although an analysis has not been conducted to determine the jurisdiction of greatest risk nor was there an attempt to estimate potential losses to state facilities due to hazardous materials

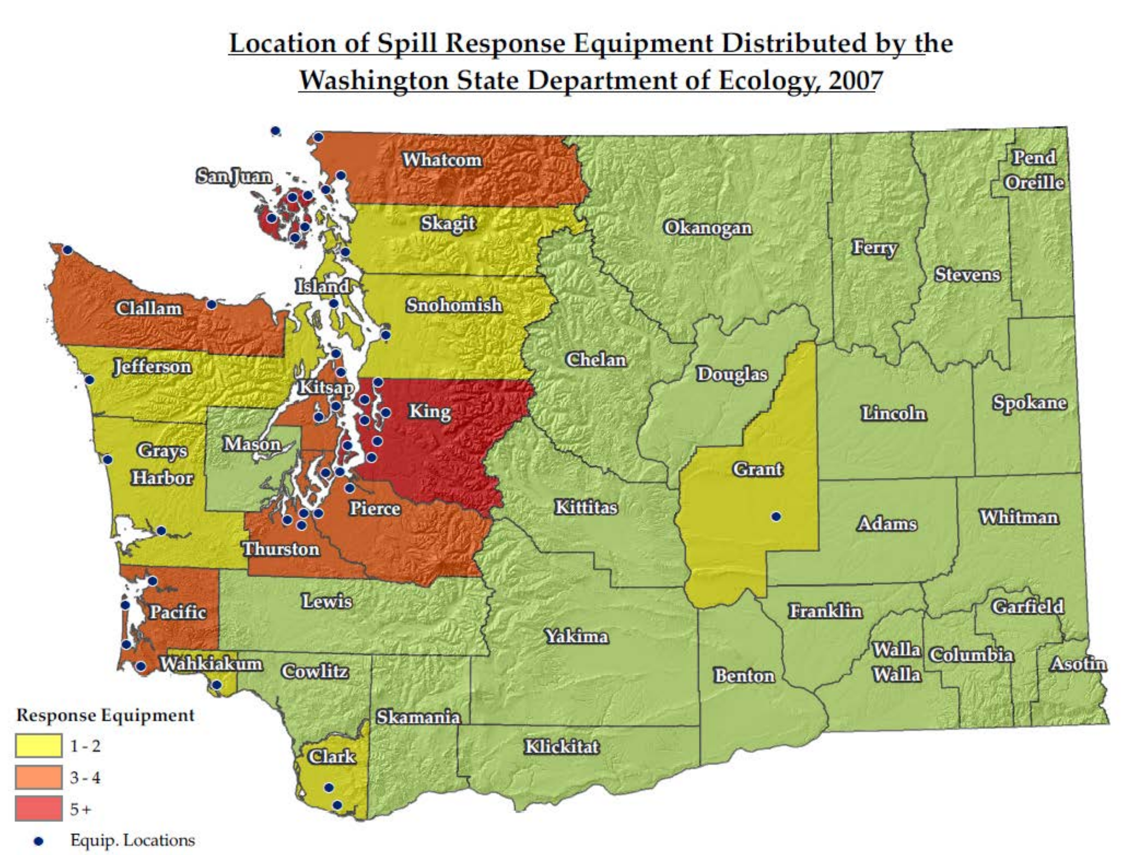


FIGURE HM8: LOCATION OF SPILL RESPONSE EQUIPMENT, INDIRECT VULNERABILITY ANALYSIS

At Risk State Facilities

This profile will not attempt to estimate potential losses to state facilities due to hazardous materials incidents. Having functional COOP plans that have been shared, trained and exercised will ensure a sense of safety and security for employees who work in facilities and locations where hazardous materials are present. Once this planning has been accomplished, ensuring that these plans have been shared with local responders and All-Hazards or Local Emergency Planning Committees will enhance a facility's survivability.

Focus areas will need to be shelter-in-place, evacuation and a reliable, functioning, in-place alert and warning system.

Pipelines Hazard Profile

Risk Summary

Frequency –A significant pipeline incident occurs in Washington approximately every one to 10 years.

People – Although people have been injured and killed by a pipeline incident, past incidents have not reached the minimum threshold for this category.

Economy- A pipeline incident can affect the major transportation routes throughout the state and could cause major disruption to movement of goods by truck, rail and air resulting in major losses to the state's economy.

Environment – Although the environment and the species that inhabit these areas can be affected by a pipeline incident due to a spill of hazardous materials, it is not felt that such an incident will eradicate 10 percent of a single species or habitat.

Property – Based on past property damage of other states as a result of a pipeline incident, an incident occurring in a heavily populated area of the state could generate property damage in the range of $100-500 million dollars.

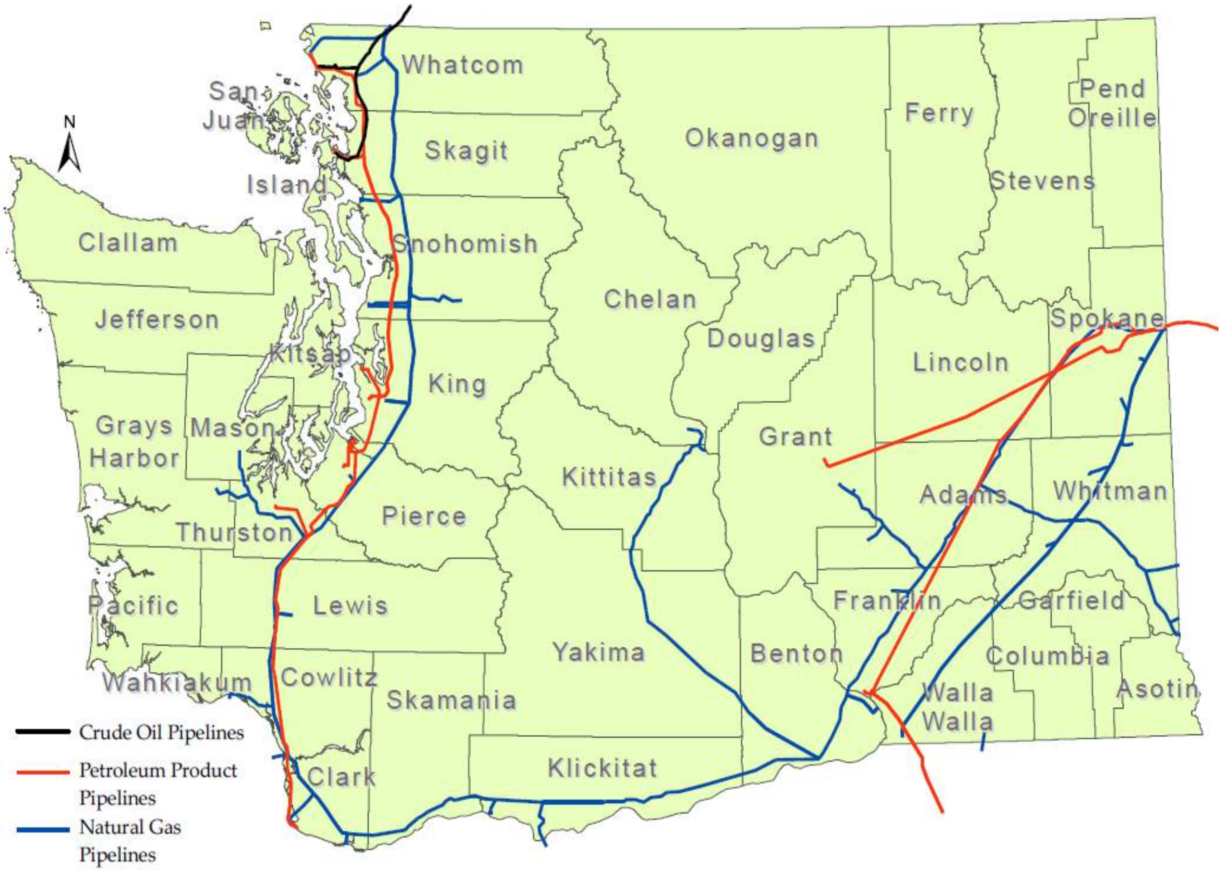


Figure HM9: Washington State Pipeline Distribution Network. The location of pipelines carrying natural gas, petroleum products and crude oil located within Washington State

Hazard Description

A pipeline is defined as a transportation artery that is capable of carrying liquid and gaseous fuels. Pipelines can be buried beneath the surface or can be placed above ground. Natural gas or hazardous liquid transmission pipelines run through 28 Washington counties and 119 cities. They lie buried at varying depths, carrying a range of volatile products and cross through a variety of land uses --from agriculture to urban centers. Most of the more than 3,200 miles of transmission pipelines in Washington were constructed in farmland bypassing urban areas.

Washington state has the following types of pipelines: crude oil, petroleum products and natural gas. These types of fuels are defined as:

Natural Gas – Underground deposits of gases consisting of 50 to 90 percent methane (CH_4) and small amounts of heavier gaseous hydrocarbon compounds such as propane (C_3H_8) and butane (C_4H_{10}).

Crude Oil – The term used to define petroleum as it comes directly out of the ground. It is a varied substance, both in its use and composition. It can be a straw colored-liquid or a tar-black or semi-solid. Red, green, and brown hues of crude oil are common.

Petroleum Products – Petroleum products is a generic name for hydrocarbons, including crude oil, liquid natural gas, natural gas and their products. Petroleum products include gasoline, kerosene, jet fuel, heavy fuel oil, diesel, petroleum jelly and paraffin.

Crude oil and petroleum products travel in the hazardous liquid line while natural gas travels in the gas transmission and gas distribution lines.

Washington State Pipeline Mileage Overview	
Pipeline System	Mileage
Hazardous liquid line mileage	839
Gas transmission line mileage	1,954
Gas Gathering line mileage	0
Gas distribution mileage (1,238,807 total services (A))	21,577
Total pipeline mileage	24,370
Source: US DOT Pipeline & Hazardous Materials Safety Administration http://primis.phmsa.dot.gov/comm/reports/safety/WA_detail1.html	

Previous Occurrences

Two state agencies have jurisdiction over pipelines. The Washington State Utilities and Transportation Commission (UTC) is responsible for the inspection and regulation of pipelines in Washington. The Commission's pipeline safety program began inspecting natural gas systems operating in Washington in 1955. Intrastate hazardous liquid pipelines were added to the Commission's responsibilities in 1996. In 2000, the Washington State Legislature approved the *Pipeline Safety Act* (HB2420), which directed the Commission's pipeline safety program to seek federal approval to include inspections of all interstate pipelines. In 2001, the State Legislature adopted the *Pipeline Safety Funding Bill* (SB 5182). In addition, in 2003, the Washington UTC became the lead inspector for all interstate pipeline inspections and incidents. The State Pipeline Inspection Program is supported through a combination of federal grants and pipeline fees. The Washington Department of Ecology is the head of the state incident command system in response to a spill of oil or hazardous substances. Ecology coordinates the response efforts of all state agencies and local emergency response personnel. Petroleum pipeline companies are required to provide Ecology with contingency plans that describe their response to oil spills should they occur. Drills are routinely conducted to test the plans.

U.S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration (PHMSA) defines a Significant Pipeline Incident as those incidents reported by pipeline operators when any of the following specifically defined consequences occur: 1) fatality or injury requiring in-patient hospitalization; 2) $50,000 or more in total costs, measured in 1984 dollars; 3) highly volatile liquid releases of five barrels or more or other liquid releases of 50 barrels or more; 4) liquid releases resulting in an unintentional fire or explosion.

Washington All Pipeline Systems: 2002 2011

Year	Number	Fatalities	Injuries	Property Damage	Gross Barrels Spilled (Haz Liq)	Net Barrels Lost (Haz Liq)
2002	4	0	0	$281,541	49	13
2003	5	0	0	$607,827	3	3
2004	8	1	2	$1,430,008	45	25
2005	3	0	0	$61,526	1	0
2006	2	0	0	$226,260	0	0
2007	1	0	0	$38,002	0	0
2008	4	0	1	$800,596	85	71
2009	6	0	2	$933,615	1	0
2010	3	0	0	$310,530	0	0
2011	6	0	3	$790,201	0	0
Totals	42	1	8	$5,480,109	187	112
2012 YTD	3	0	0	$170,500	3	0

Source: US DOT Pipeline & Hazardous Materials Safety Administration
http://primis.phmsa.dot.gov/comm/reports/safety/WA_detail1.html

Only a few notable pipeline incidents occurred in Washington in the past 15 years. Most spills from liquid petroleum pipelines have been no larger than a few gallons. The three exceptions are from the Olympic Pipe Line. On December 28, 2002, a spill of 1,465 gallons of trans-mix occurred at the Renton Control Center. This spill was caused by equipment failure and went into a containment vault. No oil was released into the environment. On May 23, 2004, a breach in a 3/8 inch sampler line caused a release of 1,890 gallons of gasoline, also at the Renton Control Center. The gasoline subsequently caught fire and burned the sampling shed. Some of the gasoline was released to the environment. The largest release in Washington in recent years was from Olympic Pipeline when the pipeline ruptured, caught fire and exploded at Whatcom Falls Park in the city of Bellingham on June 10, 1999. The ruptured line leaked 277,000 gallons of gasoline into a creek bed and resulted in three casualties.

On February 8, 1997, a natural gas pipeline caught fire and exploded near Everson, WA, in Whatcom County. The explosion occurred in a remote area of mostly wooded and mountainous terrain, which was a former glacier slide area. The 26-inch pipeline involved in the explosion failed due to ground movement of water-saturated soil. The following day, a natural gas pipeline caught fire and exploded near Kalama, WA, in Cowlitz County. This explosion also occurred in a remote area and was the result of ground movement that caused a break at a weld within the pipeline resulting in the explosion.

Pipeline incidents often occur due to problems such as corrosion. Corrosion is the deterioration of metal that results from a reaction with the environment which changes the iron contained in pipe to iron oxide (rust). Corrosion can occur on the external and internal portions of the pipe and can result in the gradual reduction of the wall thickness and a resulting loss of pipe strength. This loss of pipe strength can then result in leakage or rupture of the pipeline due to internal pressure stresses unless the corrosion is repaired, the affected pipeline section is replaced, or the operating pressure of the pipeline is reduced. Pipeline corrosion creates weakness at points in the pipe, which in turn makes the pipe more susceptible to other risks such as third-party damage, overpressure events, natural disasters, etc.

Events such as flooding and earthquakes can increase the likelihood of a pipeline incident. The Northridge Earthquake occurred on January 17, 1994, and damaged buildings, highways, and other structures in Southern California. In addition to building and highway damage, this earthquake damaged several crude oil underground pipelines in the area. One of these pipelines ruptured and spilled 177,000 gallons of crude oil into a storm drainage system, which flowed into the Santa Clara River. The crude oil flowed down the river for about 16 miles causing extensive environmental damage.

Heavy rains and catastrophic flooding of the San Jacinto River near Houston, Texas, caused eight oil pipelines to rupture and burn on October 19-20, 1994 (Figure 2). The surging floodwaters of the river washed away soil over and under the pipelines involved in the incident, exposing them to intense hydraulic pressures that bent and twisted them until they eventually burst. These pipeline ruptures spilled an estimated 2.5 million gallons of crude oil, refined petroleum products and liquefied petroleum gas into the river and Galveston Bay. The fires

Figure 10: San Jacinto River Flooding and Pipeline Explosion, October 19-20, 1994

resulting from this incident caused extensive damage to many structures that were thus unaffected by the flooding and injured an estimated 1,830 people.

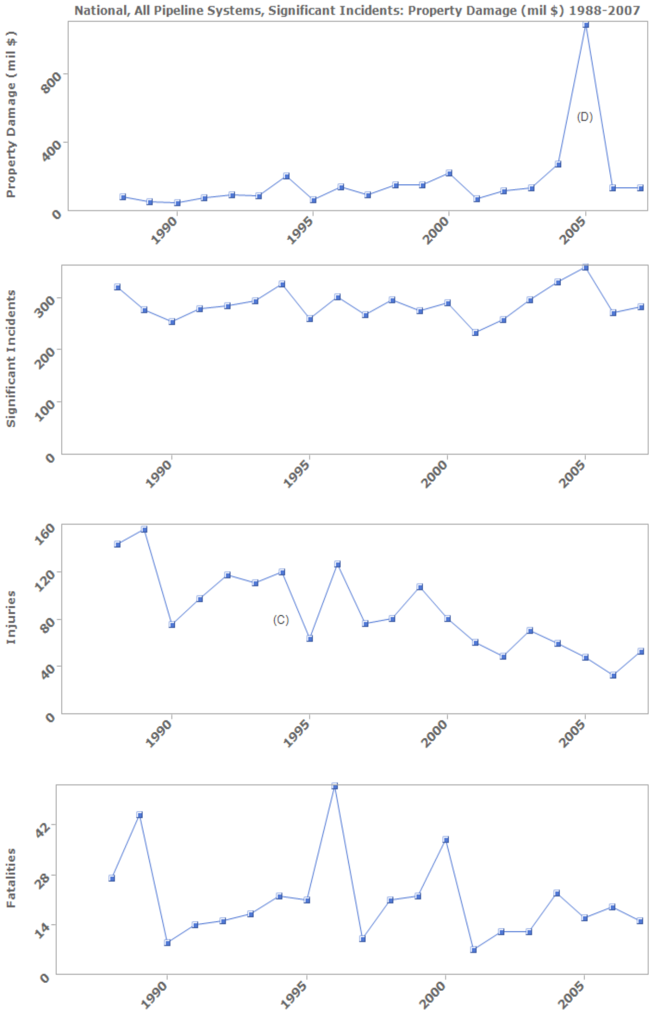
Although only affecting the immediate area in which these incidents occur, these spills illustrate the vulnerability of pipelines in earthquake-prone and flood prone areas. Pipeline vulnerabilities to both earthquakes and flooding should be considered when designing and building new pipelines due to the history of these events in Washington.

Probability of Future Events

There are 30 pipeline companies in Washington with the responsibility for the operation of 24,000 miles of pipelines. More than 22,000 miles of pipeline provide natural gas to residential neighborhoods and more than 700 miles of pipeline carry gasoline, diesel, jet fuel, crude oil and butane. Twenty-one of the 30 pipelines carry natural or hydrogen gas and 10 of these carry hazardous liquids such as crude oil, gasoline and jet fuel. There are nine interstate pipelines in Washington – five carry liquids and three carry natural gas. Interstate pipelines typically are large diameter pipelines that operate at very high pressures.

The transportation of hazardous liquids and gases is safer by pipeline than by any other means (Figure 3). However, if an incident occurs at a pipeline the results could be disastrous. With the continued expansion of the population in the state, especially the Puget Sound region, many people now live closer to pipelines then were originally planned. Many of these pipelines are within a few blocks of schools and in one case in Pierce County, actually run under a school playground. A major break in a pipeline at one of these locations could not only shut down major transportation routes for a short period of time to deal with the response but could affect a large portion of the community in which the event occurs.

Pipeline incidents are the results of a rupture or break in a pipeline that causes a spill and sometimes a fire or explosion. The hazardous liquids spilled from the pipeline can damage streams, rivers and other sensitive areas. Ignition of the hazardous liquids from the pipeline can damage sensitive areas, habitat and residential and commercial property.



U.S. Pipeline Significant Incidents from 1988-2007

Populations near pipelines are potentially vulnerable to an incident. Pipelines near rivers or streams with a history of flooding, as well as those on or near earthquake faults or landslide areas are vulnerable to an incident. Additionally, pipelines near and around excavation work are vulnerable to an incident.

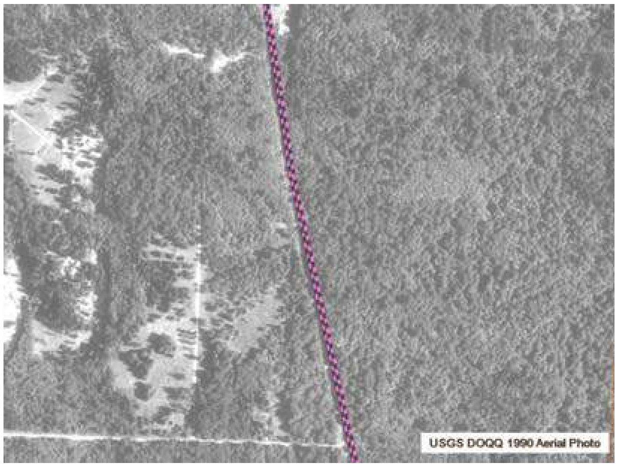
The best way to reduce the number of pipeline incidents occurring in Washington is to have pipeline companies fully comply with the safety measures set forth in the Washington State Pipeline Safety Act and for the Washington Utilities and Transportation Commission (UTC) to make regular inspections of pipelines. After a third party, earthquake or flood incident, the pipeline company should provide an immediate inspection, spill prevention and cleanup of damaged sections of the pipeline. The Washington Department of Ecology should oversee incident response for larger ruptures or breaks.

Possible broad mitigation strategies for reducing the vulnerability and risks associated with pipelines include: pipeline integrity management assessments; enhancing public education and awareness on the hazards of pipelines and their location near communities and populated centers; improving communication and information sharing between pipeline companies and local government agencies, particularly those involved with land-use planning and emergency management and response; and enhancing pipeline company support and cooperation with local emergency first responders.

Washington's UTC Pipeline Safety Program participated in land use research to integrate mitigation land use planning efforts. The presence of a pipeline forms a relationship between pipeline operator, local government and property owner. How this relationship is managed can affect directly the safe operation of the pipeline and consequently the public health and safety of the surrounding community. In 2004 and 2005, a group of city, county, state and industry representatives conducted a series of workshops throughout the state for local government officials, talking in particular with the planning, permitting and public works sections. The purpose of these workshops was to exchange ideas and explore the range of tools available to manage and make effective decisions concerning land use in proximity to transmission pipelines. This report titled *Land Use Planning in Proximity to Natural Gas and Hazardous Liquid Transmission Pipelines in Washington State, June 2006* is the product of that research.

Jurisdictions most Threatened and Vulnerable to Pipeline Hazards

Most of the more than 3,200 miles of transmission pipelines in Washington were constructed in farmland bypassing urban areas. However, to accommodate population and economic growth, land areas once considered rural are being absorbed into expanding urban growth areas and developed to urban uses.



1990

2002

Nine of the state's 10 fastest growing counties in 2005 are home to almost half of the state's major pipeline mileage. This growth means more and more people are working and living near major pipelines. Increases in population and land use activity expand the risks of pipeline damage and raise the stakes in the event of a pipeline incident. The pictures above were taken of the same area in Washington State – 12 years apart

Pipeline safety and environmental regulations have generally focused on the design, operation and maintenance of pipelines and incident response. They have not directed significant attention to the manner in which land use decisions in proximity to pipelines can affect public health and safety. Building codes and development regulations for critical areas, seismic resiliency, fire prevention, etc. work. Now this methodology is being applied to pipelines.

Crude by Rail

Movement of crude oil by rail in Washington state began in 2012 and has continued to increase since that time. Rail routes transporting crude oil enter the state from Idaho near Spokane and from British Columbia near Bellingham. Large portions of the rail routes travel along the I-5 corridor and cross or run next to major waterways, including the Columbia River and the Puget Sound (see below for a map of railroad routes in the state.)

For the first quarter of 2017, the total number of barrels of crude oil transported in Washington state was 12,142,580, of which 94 percent originated in North Dakota. This equals more than 18,000 tank cars. All of the crude oil originating from North Dakota was light crude.

As can be seen by the above map much of this highly volatile cargo moves through the most densely populated regions in the state. Most significantly, the oil train routes pass through the downtowns of Spokane, Pasco, Vancouver, Tacoma, Seattle and Everett, exposing these high-density population centers to this possible hazard.

Hazardous Materials Releases and First Responders

To mitigate the impacts of a hazardous material incident, Washington has developed a three-tiered approach to hazardous materials response. For each level, the state has developed a specific training program.

- Awareness Level – for anyone who may be in a situation where they need to identify that a hazardous material incident has or is occurring. This training ensures that those that might be in position to first identify an incident understand basic hazard and risk assessment techniques, how to select and use proper personal protective equipment, an understanding of basic hazardous materials terms, how to perform basic control, containment and/or confinement operations, how to implement basic decontamination procedures, an understanding of the relevant standard operating procedures and termination procedures and an understanding of Weapons of Mass Destruction and how to detect that they may have been used.

- Operations Level – This is designed for first responders such as firefighters and law enforcement that could be called to a hazardous material incident scene. Those wishing to take operational level training must complete Awareness Level training. Operational Level training increases a first responder's understanding of hazardous material response. Most professional firefighters in the state have completed this level of training. Those who complete this training will have the knowledge of the basic hazard and risk assessment techniques, how to select and use proper personal protective equipment, an understanding of basic hazardous materials terms, how to perform basic control, containment and/or confinement operations, how to implement basic decontamination procedures, an understanding of the relevant standard operating procedures and termination procedures and an understanding of Weapons of Mass Destruction and how to detect that they may have been used. Operations Level personnel will operate in a defensive manner and will not operate in the HOT ZONE, with their efforts focused on mitigating the incident impacts outside the HOT ZONE.
- Technician Level – This is offered to those who wish to acquire the specialized skills needed to effectively respond to a hazardous material Incident. Technicians will select and use proper personal protective equipment for the hazards presented. They will operate in an offensive manner in order to mitigate the incident.

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Landslide Risk Summary

Washington State Risk Index for Landslides (WaSRI-L)	**MEDIUM-HIGH**
LIKELIHOOD	HIGH
The State experiences landslides almost annually. The annual probability of multiple landslides is 0.82 (82%) (based on 2001-2017 data)	
HAZARD AREA	HIGH
54% of the State is exposed to medium or higher landslide hazard.	
POPULATION	MEDIUM
21% of the State population is exposed to medium or higher landslide hazard.	
VULNERABLE POPULATION	MEDIUM-LOW
6% of total urban area in the state is both, ranked medium or higher on social vulnerability, and is also exposed to landslides.	
BUILT ENVIRONMENT	MEDIUM
21.5% of the general building stock of the State is in areas exposed to landslides	
CRITICAL INFRASTRUCTURE	MEDIUM-HIGH
42% of the facilities are in areas exposed to medium or higher landslide hazard.	
STATE FACILITIES	MEDIUM
26% of State Owned facilities are in areas exposed to medium or higher landslide hazard. 25% of the State Leased facilities are in in areas exposed to medium or higher landslide hazard.	
FIRST RESPONDERS	MEDIUM
23% of the Fire Stations are in areas exposed to medium or higher landslide hazard. 21% of the Law Enforcement facilities are in areas exposed to medium or higher landslide hazard. 23% of the EMS facilities are in in areas exposed to medium or higher landslide hazard.	
ECONOMIC CONSEQUENCES	MEDIUM-LOW
Counties ranked high or medium-high on WaSRI-L account for 10% of real State GDP.	
ENVIRONMENTAL IMPACTS	HIGH
56% of critical environmental areas are exposed to landslide hazard.	

Landslide Hazard Profile

Hazard Description

Washington is one of the most landslide-prone states in the country and annually experiences hundreds to thousands of events (www.dnr.wa.gov, n.d.). The word landslide captures a wide variety of processes, material, and behavior (Highland 2004). Landslides can vary in size from a few cubic yards to areas in excess of tens to hundreds of acres. Landslides can be slow and move fractions of an inch per year or travel very rapidly, such as the SR530 "Oso" landslide calculated to have moved about 60 miles per hour (Keaton, et.al, 2014). Landslides are often driven by precipitation events which can vary in intensity and duration. Some landslides will initiate from short duration and high intensity precipitation events over a few hours or days, while other landslides may initiate due to months or years of above average precipitation (PNSN, n.d.). They can also be generated by earthquakes and related ground shaking.

Landslide debris may move only a short distance with the deposits collecting at the base of the landslide source area, and other landslides can travel for dozens of miles in narrow valleys, potentially impacting people far from any perceived hazard (landslides.usgs.gov, n.d.). These complex and seemingly disparate characteristics of landslides make it difficult to assess or understand the hazard and risk of potential landslides.

Landslide is a general term used to describe the downslope movement of soil, rock, debris, and earth materials under the influence of gravity (Cruden 1991). Landslide is also often used as a descriptor of the landform that results from such movement. Geologists classify landslides based on the type of landslide movement and the landslide material (Varnes 1958). Forming names is typically a compound word with the first word describing the material and the second word the movement type. Materials typically described are *rock*, *debris*, and *earth*. Movement type includes *falls*, *topples*, *slides*, *spreads*, *avalanche*, and *flows*. The combination of these descriptions results in the landslide classifications, such as *debris flows*, *rock topples*, *earth flows*, etc. The compound name can classify a landslide and help geologists assess the landslide hazard and the potential mitigation solution(s) (Highland 2004).

Landslides may be further categorized by describing the depth of the failure surface, either deep or shallow (Cruden and Varnes 1996; Highland 2004). A shallow landslide failure surface often occurs at the interface between the soil and underlying bedrock or other geologic material. Whereas deep landslides have a failure surface in bedrock or other geologic material such as glacial deposits, weathered bedrock, and other geology that may not be identified as bedrock. Generally, shallow landslides tend to be rapid and are initiated by short periods of prolonged or intense precipitation, whereas deep landslides tend to be slower and initiated by weeks, months, or years of above average precipitation.

Contributing factors that may initiate a landslide are complex. Shallow landslides can be initiated from disturbing vegetative canopy, grading slopes, focusing water, short periods of prolonged or intense precipitation, rain-on-snow events, and others. Shallow landslides tend to occur on slopes and may initiate adjacent to where similar shallow landslides have occurred in the past. Deep landslides tend to be present on the landscape and are "reactivated" due to outside influences. These dormant landslides may have initiated centuries to thousands of years ago and have been responsible for some of the greatest landslide tragedies in the country. Such events include the SR530 "Oso" landslide that took 43 lives or the Aldercrest-Banyon Landslide that destroyed more than 120 homes (Buss et. al. 2000). Influences that may initiate reactivation include grading the landslide by removing or adding mass; weeks, months, or years of above average precipitation; erosion of the landslide from a river or waves; or other factors. Figure L1 identifies the position and the terminology used to describe common parts of a landslide (Highland 2004).

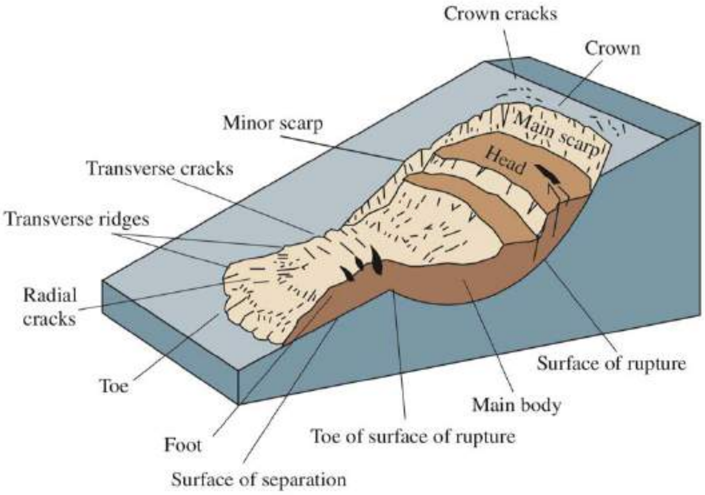


FIGURE L 1: LANDSLIDE CHARACTERISTICS (SOURCE: HIGHLAND 2004)

Landslides, especially those that may be initiated by high intensity and short duration precipitation and (or) rain-on-snow, are often associated with flooding events. Because of this, FEMA loss estimation conflates the flooding event to the landslide event, making it difficult to differentiate the two when examining direct and indirect costs. Direct costs of landslide damage include the repair of physical infrastructure and other property. Often, indirect costs, such as loss of property value and tax revenue, and degradation of environmental resources, far exceed the direct costs.

In some situations, debris-laden flash floods or muddy streamflow may be called a mud flow, debris flow, or other terms that classify the stream flow as a landslide. Non-geologists often consider these events as landslides, which is scientifically inaccurate. A flash flood or muddy stream flow is not a landslide, though the event may have been triggered by a landslide. The watered-down, debris-laden stream flow witnessed far downstream should be carefully examined to ensure a proper classification.

Factors Contributing to Landslide

Natural Factors: Geomorphological factors contributing to landslides include slope morphology (shape), slope material (soil), bedrock geology, vegetation, and climate (Highland and Bobrowsky 2008). Generally, the steeper a slope, the more prone it is to landslides. The general shape of a slope also influences the likelihood of a landslide. On a concave slope, water and debris tend to concentrate, making landslides more likely. Conversely, on a convex slope (e.g., ridge, nose), water and debris are less likely to accumulate; therefore, landslides are less likely on such slopes.

The slope surface materials and their underlying geology also influence potential for both shallow and deep landslides. Strongly weathered bedrock that may be fractured and altered to a weaker material is more susceptible to a landslide than a slope made up of solid rock. In the Puget Sound area, a common landslide initiation area is on the steep bluffs along the shoreline (PNSN, n.d.). An underlying clay layer that is impermeable to water underlays a permeable sand layer. Ground water will flow through the sand layer and then accumulate on the impermeable clay, leading to saturation of the sand. As the groundwater flows towards the bluffs, the saturation weakens the sand, making it more susceptible to landslides.

Presence of vegetation contributes to slope stability primarily for shallow landslides (Steinacher et al 2009). Deep roots of trees and shrubs penetrate the soil and increases the soil's shear strength. Even as the soil becomes saturated, the root strength increases the relative strength of the soil, reducing the likelihood of shallow landslides. Conversely, lack of vegetation increases the likelihood of a landslide.

Precipitation events (intensity, duration, and timing) significantly influence the potential for initiation of deep and (or) shallow landslides. Local climatic conditions can influence the processes of rock weathering (important in influencing soil depth and rock strength). Other factors that can contribute a landslide initiation include the type of vegetation that occupies the hill slopes, the slope morphology, and the fire regime of a region. Consequently, higher frequency of landslide initiation is observed in the wetter months of late autumn and winter (PNSN, n.d.).

Human Activities: A number of human activities and land uses can increase the potential for landslides (Cornforth 2005). These activities include slope modification (construction, grading, etc.), forest harvesting, grazing, mining, and others similar landscape-altering actions. Such activities contribute to slope instability by changing infiltration rates, directing surface water flow onto the slope, removal of vegetation, and (or) over-steepening slopes.

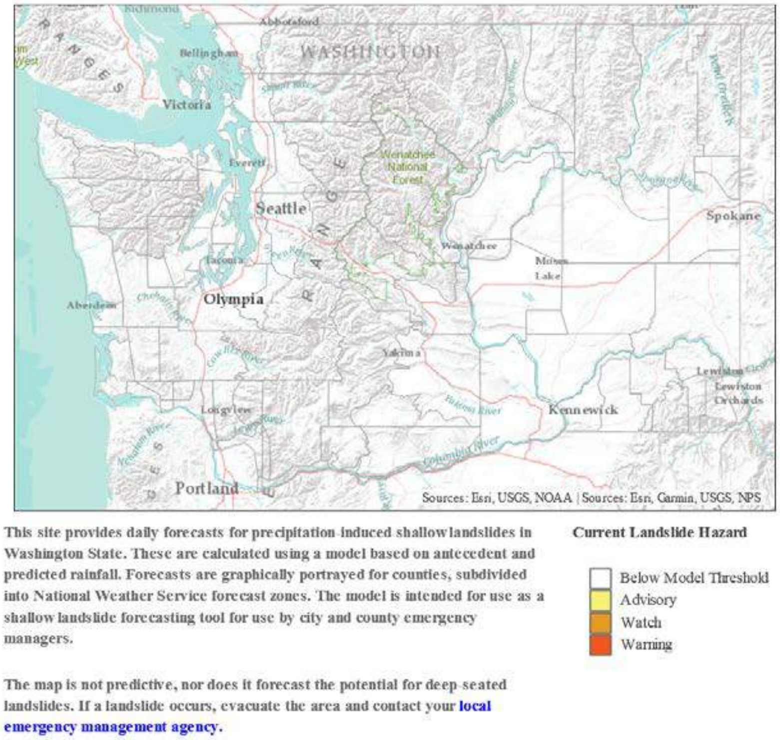
Increase in soil moisture through irrigation and other ways (e.g., sprinklers, injection wells, and even septic systems) may also contribute to local slope instability. Development of roads on steep slopes has been widely identified as the single human activity most likely to increase the landslide hazard on a site. Roads increase the amount of exposed soil. Mining activities can have similar impacts.

Landslide Triggers

Typical triggering events include (alone or in combination): water, rapid snowmelt, water-level change (such as during times of rapid drawdown in a reservoir), seismic activity, volcanic eruptions, and the rapid erosion of the slope toe material (e.g., by stream down-cutting or road excavation). Intense rainfall and rapid snowmelt, often combined with impact of human activities, are the frequent cause of landslides (Case 2001).

A common cause of slope failure is the infiltration of water, which usually leads to an increase in ground stresses and a reduction of the soil's strength. Late autumn through early spring are when landslides typically occur, particularly after days and weeks of greater than normal precipitation.

Washington Geological Survey maintains a landslide hazard forecast map that provides daily forecasts for precipitation-induced shallow landslides in Washington State. These are calculated using a model based on previous and predicted rainfall. Forecasts are graphically portrayed for counties, subdivided into National Weather Service forecast zones. The model below is a beta version and is intended for use as a shallow landslide forecasting tool for use by city and county emergency managers.



Sources: Esri, USGS, NOAA | Sources: Esri, Garmin, USGS, NPS

This site provides daily forecasts for precipitation-induced shallow landslides in Washington State. These are calculated using a model based on antecedent and predicted rainfall. Forecasts are graphically portrayed for counties, subdivided into National Weather Service forecast zones. The model is intended for use as a shallow landslide forecasting tool for use by city and county emergency managers.

The map is not predictive, nor does it forecast the potential for deep-seated landslides. If a landslide occurs, evacuate the area and contact your local emergency management agency.

Current Landslide Hazard

☐ Below Model Threshold
🟨 Advisory
🟧 Watch
🟥 Warning

FIGURE L2: DNR SHALLOW LANDSLIDE FORECAST MAP (ACCESSED 4/1/2018)

Seismic activity and volcanic eruptions, due to their infrequent occurrence, play a relatively minor role in triggering landslides in Washington. The 1980 eruption of Mount St. Helens, considered one of the world’s largest landslides, involved the flank of the erupting volcano sliding to the north and burying miles of forest and Spirit Lake. Seismically induced landslides can trigger hundreds to thousands of landslides in a large area. For instance, the 2008 Sichuan earthquake in China, a magnitude 8.0 earthquake, triggered in excess of 15,000 landslides that buried villages, blocked rivers, and highways.

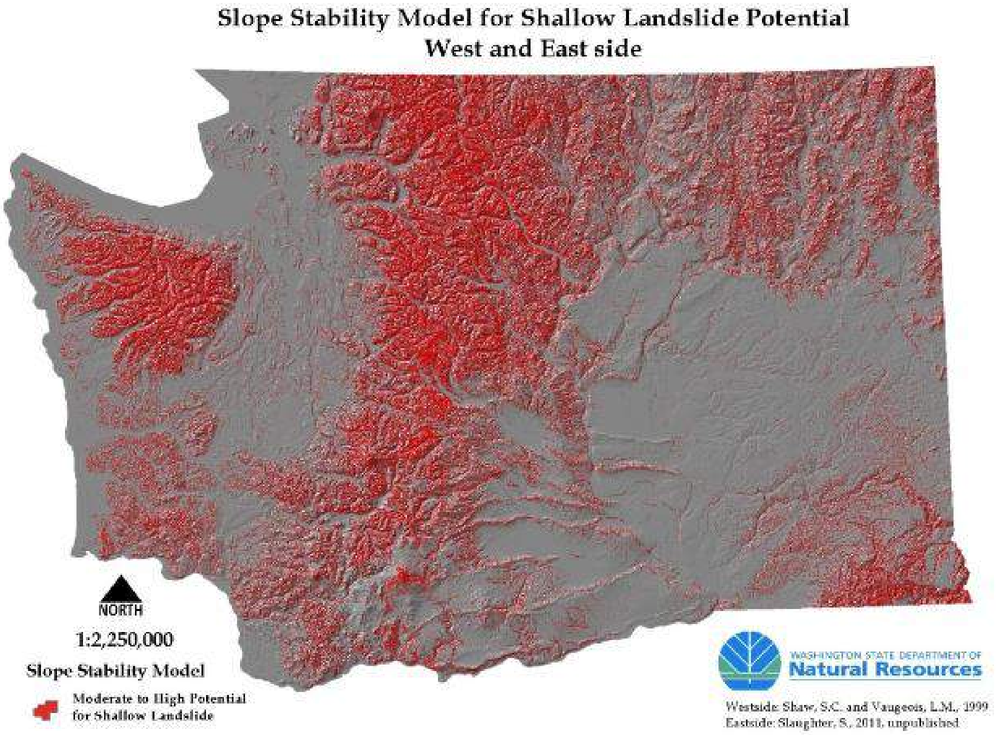
Landslides range from very small to massive, and they may affect only a single property or slope or an entire drainage area. A landslide event may be composed of a single discrete landslide or numerous landslides over an entire region. Landslides threaten residences, businesses, transportation corridors, fuel and energy lines, and communication facilities.

)

Landslide Hazard Location, Extent, and Magnitude

Landslides tend to occur in areas on or near previous landslides. For instance, a forested slope that experiences a precipitation-induced shallow landslide, could experience a similar landslide under similar conditions. Conversely, it may not, which complicates assessing landslide hazards. With deep landslides, the primary hazard is reactivation of a dormant landslide where people may have constructed infrastructure, homes, etc. Where records have been kept, landslide inventory maps can provide a useful first level view of areas where landslide may have occurred in the past. However, many landslide inventories are inaccurate, so it is best to consult a geologist when reviewing landslide hazards from mapping.

Areas typically susceptible to landslides are steep hillsides (20 degrees and greater) and convergent topography. Landforms can also be a factor in landslide susceptibility, such as areas of steep shoreline bluffs, colluvium hollows (bedrock hollows), inner gorges, meander bends, rugged topography (mountainous terrain), and on deep landslides. Features such as alluvial fans may be a hazard for flooding and debris flows.



Westside: Shaw, S.C. and Vaugeois, L.M., 1999
Eastside: Slaughter, S., 2011, unpublished

FIGURE L3: SLOPE STABILITY MODEL

Analysis of landslide risk to local jurisdictions is difficult. Currently, there are no comprehensive statewide landslide hazard maps. However, some models exist to aid in identifying an area’s susceptibility to landslides. Earthquakes have the potential to cause landslides in both Eastern and Western Washington. Landslide risk is higher in Western Washington due to the greater amount of precipitation. Water and gravity are the main drivers of landslides. In Eastern Washington, the landslide risk is high during storm events (especially spring and summer thunderstorms) and in places where irrigation is near bluffs or near or on deep-seated landslides. It is expected that forest stresses related to climate change, and associated increases in wildland fires, will increase the likelihood of landslides and soil mobilization in this region (Miles et. al. 1989; Helvey et. al. 1976).

Geologists at the Department of Natural Resources are developing large-scale, high-quality landslide inventories using LiDAR derivatives to map landslides. Eventually, this mapping effort will cover all populated areas statewide at risk to landslide. According to DNR, the landslides are delineated with polygon and line features as well as given 17 unique attributes. A percentage of the landslides are field-checked, and all landslide polygons are reviewed by a licensed geologist. The data is assembled into a database and susceptibility maps are produced using the data.

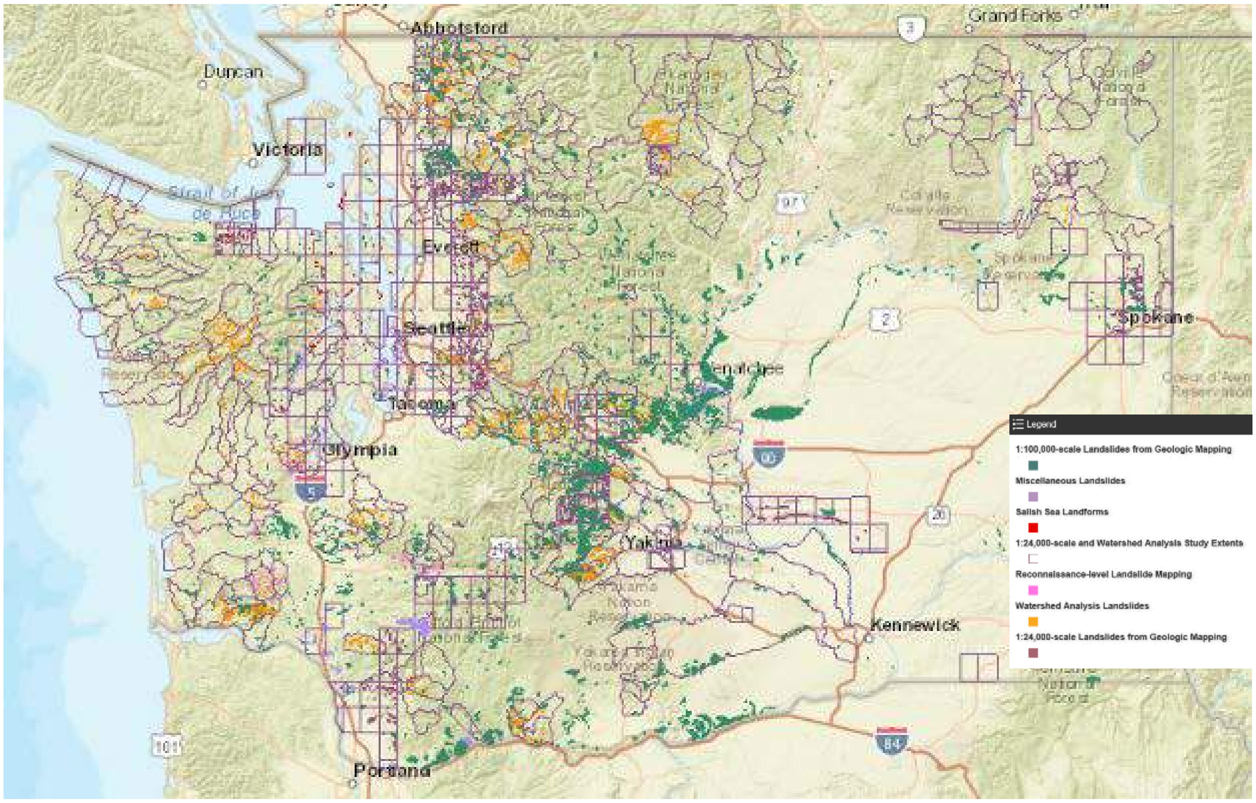


FIGURE L4: LANDSLIDE INVENTORY MAP

The above map is the most comprehensive landslide inventory map available. It includes recently completed work surveying Pierce County, detailed mapping study areas, and both shallow and deep landslide susceptibility. While landslide polygons indicate areas where landslides have occurred, landslide susceptibility attempts to highlight areas that could experience a landslide in the future.

Washington Landslide Hazard Provinces

Washington has six landslide provinces, each with its own characteristics.

Puget Lowland – North Cascade Foothills

This landslide province is the portion of the Puget Lowland overridden by ice during the last continental glaciation. It has abundant rain, or in the foothills, rain and snow. This province has the largest and fastest growing population in the state.

Unconsolidated glacial soil material lies on top of bedrock in the lowland, sculpted, and compacted by the last continental ice sheet. During the retreat of the continental glaciers to the north, extensive glacial melt water eroded deep channels in the unconsolidated glacial sediments, resulting in over-steepened, unsupported slopes like those in Hood Canal, the Tacoma Narrows, and Lake Sammamish. The channels left by the earlier glacial runoff, combined with the precipitation runoff in typical northwest maritime climate and Puget Sound wave action, has cut hundreds of miles of steep bluffs into the thick, unconsolidated glacial sediments. Many bluffs are in or near population centers; demand for residential development is great on these bluffs because of the economic value of views from the top or access to the beach below. Slope stability maps of the Coastal Zone Atlas (Washington Department of Ecology, 1978-1980) show more than 660 miles of bluffs as unstable.

Four landslide types affect these bluffs:

- *Slump* – This type of landslide occurs when groundwater concentrates on layers of compact silt or clay in the lower bluff area; the existence of a saturated zone can cause the sands and gravels in the upper bluff to subside. Slumps tend to leave a distinctive mid-bluff bench; examples are found in the Alki, Fort Lawton, and Golden Gardens areas of Seattle, Scatchet Head on Whidbey Island, and the Thorndyke Bay area of Jefferson County.
- *Debris flows* – Excessive groundwater combined with focused surface runoff during heavy precipitation can turn a landslide into a debris flow, which occurs rapidly and typically accelerates with down-slope movement. These types of landslides are usually responsible for a majority of the lives lost to landslides around the world annually. Debris flows typically contain trees and large woody debris suspended in a wet, concrete-like soil mixture that can cause loss of, or significant damage to, structures and property. Debris flows that reach a high enough speed can create a localized tsunami wave.
- *Dormant to relict deep-seated landslides in unconsolidated materials* – Dormant and relict deep-seated landslides in the thick glacial sediments of the Puget Sound lowlands are a concern because of their large size, the difficulties the average citizen has in recognizing them, and development pressure, especially in shoreline areas. Reactivation of such landslides generally occur slowly, consisting of a few feet of movement in a particular episode, usually in late winter or early spring after an unusually wet or series of wet winters. Even a small amount of movement can cause severe damage to structures and utilities.
- *Submarine landslides* – Submarine landslides typically occur on submarine deltas (common in Hood Canal) and along steep submarine bluffs, typically formed by glacial processes. These landslides are apt to go unnoticed unless they trigger noticeable water waves or damage submarine utilities. They have the potential to generate localized tsunamis in Puget Sound.

The Northern Cascade foothills are susceptible to landslides in bedrock. The foothills are subject to moist Pacific storms; the shape and contour of the foothills enhance the amount and intensity of precipitation. Recent studies following the January 7-9th, 2009 storm suggests shallow landslides predominantly occur on the Chuckanut Formation. Deep-seated landslides appear to be more common in the phyllitic rocks, such as the Darrington Phyllite.

- *Debris flows* – These slides commonly enter confined, steeply inclined, flood-swollen stream valleys, becoming more mobile than that of an isolated coastal bluff debris flow, capable of traveling miles from their point of origin. These predominantly deposit on alluvial plains at the base of the hills.
- *Bedrock landslides* – These landslides are in folded and faulted sedimentary and phyllitic rocks that outcrop along the edges of the northern lowland. Nearly all are dormant to relict deep-seated landslides that move by two predominant factors: removal of support by retreating glacial ice, glacial melt-water erosion over-steepening the valley slopes, or strong ground shaking during earthquakes.

Southwest Washington

The primary characteristics of this landslide province are the lack of glaciation and localized exposure to glacial melt water. In places, weathering processes have exposed much of the surface in this province for millions of years. Much of the province has deeply dissected terrain, with areas of mid-slope benches and gentle slopes at the toe of mountain slopes. Recent studies following the December 3, 2007 storm indicate that Crescent and related intrusive rocks are the dominant lithology where shallow (debris flows and debris avalanches) occur. The deep-seated landslides (earthflows and other deep-seated) occur predominantly in the surrounding marine and nearshore sediments.

- *Earthflow* – This is the dominant form of deep-seated landslide in the province. Relict, dormant, and active earth flows are common, not only in the higher steep terrain, but also in the lower rolling hills of the Chehalis-Centralia area. Stream erosion along the toes of the earth flows usually causes reactivation of these landslides. Excavations, such as those for freeway construction, also may reactivate dormant earth flows or initiate new ones.
- *Dormant to relict deep-seated landslides in the Willapa Hills* – Dormant to relict deep-seated landslides in the Willapa Hills of southwest Washington are a concern because of their large size and impact on commerce and utility corridors for the rural coastal communities here. These deep-seated landslides typically occur along the weathered soil interface with the bedrock. Reactivation of such landslides generally occurs slowly, consisting of a few feet of movement in a particular episode, usually in the late winter or early spring after an unusually wet winter or during intense precipitation events. Even a small amount of movement can cause severe damage to structures and utilities. It is likely that a number of the large dormant to relict landslides in the Willapa Hills failed during strong ground shaking in this area.

- *Debris flows and Debris Avalanches* – These types of landslides are a widespread problem in the Willapa Hills and foothills to the western Cascade Mountains; they tend to occur where the rocks have steep slopes and smooth surfaces overlain by thin soils. Debris avalanches can cause a rapid movement of material down the hill, blocking rivers and streams and creating temporary debris dams. Both debris avalanches and debris flows can deposit a tremendous amount of debris into fluvial systems, creating large debris dams behind bridges and natural constrictions. Intense rainstorms, or rain on snow events in the mountains trigger these rapidly occurring landslides.

Cascade Range

This landslide province has a number of different landslide types because of its volcanic and alpine glacial history and climate. There are three sub-provinces in the Cascades – north of Snoqualmie Pass, south of the pass, and the strato-volcanoes, which have distinct slope stability characteristics.

The Cascades north of Snoqualmie Pass are steep and rugged, generally composed of old, strong granitic or metamorphic bedrock. The valley walls typically produce small to very large rock falls. Large deep-seated landslides, from relict to active, dot the landscape. Debris flows and to a lesser extent debris avalanches are common during prolonged, intense rainstorms and during rain on snow events. Some of these landslides have probably been triggered by strong seismic shaking.

South of Snoqualmie Pass, the peaks are primarily composed of younger volcanic sediments and rock; deep-seated landslides, earthflows and block slides in bedrock are common throughout the area. Debris flows, and to a lesser extent debris avalanches, are common during prolonged, intense rainstorms and during rain on snow events. Large deep-seated landslides in volcanic sediments and bedrock occur in the Columbia River gorge area of the southern Cascades; more than 50 square miles of landslides are in the gorge, but less than 10 percent of the area is active.

The state's five strato-volcanoes – Mount Baker, Glacier Peak, Mount Rainier, Mount St. Helens and Mount Adams – have layers of strong volcanic rock and weak volcanic rock lying parallel to the slopes. These volcanic deposits are prone to failure, with the weaker rock layers on the upper slopes weakened by hydrothermal action. Small rock falls and rock avalanches are common localized hazards on the slopes of the volcanoes; but earthquakes have triggered large rock avalanches. These volcanoes can also produce long distance and widespread lahars (also known as volcanic debris flows), which potentially can occur without an eruptive activity.

Climate changes are resulting in wetter warmer winters and hotter drying summers stressing Cascade forests. This along with increased beetle populations are increasing wildland fire risks and associated soil mobilization and landslides (UW-IHMPR 2017).

Okanogan Highlands

This landslide province extends from the slopes of the North Cascades in the west to the foothills of the Selkirk Mountains in the northeast corner of the State. The primary slope stability problem is sediments deposited by repeated damming of the Columbia River through lobes of the continental glacier ice sheet and repeated catastrophic floods from breached ice dams in western Montana.

Debris flows can be a hazard in this area during intense thunderstorms, usually moving through the area during late spring to late summer. The debris flows are generally sparse and due to a sparse population, damage is usually minimal. Deep-seated landslides are most common in the areas surrounding Lake Roosevelt. Deep-seated landslide movement usually occurs in areas where relict to dormant deep-seated landslides exist. Landslide activity was greater when the lake levels were rapidly drawn down for flood control and power generation, but since this type of activity has been largely discontinued, landslides rarely occur from it. Some landslide complexes extend for thousands of feet along the lakeshores, have distinct landslide head scarps in terraces 300 feet or more above reservoir level and extend well below the surface of the water. One hazard in this setting is water waves (inland tsunamis) generated by very large and fast-moving (debris avalanche type) landslides.

Similar to the Cascade Range, the Okanagan Highlands landslide risks are increasing with our changing climate.

Columbia Basin

This province is largely composed of thick sequences of lava flows known as the Columbia River Basalts. These lava flows can be traced from the Oregon, Washington, and Idaho border, where they were erupted from fissures in the ground, to the Pacific Ocean along the northern Oregon and southern Washington coasts via ancestral channels of the Columbia River. Sediments, sometimes thick sections, can be found between these voluminous lava flows in the Columbia Basin. These sediments are generally thicker in the western part of the province.

Between 15,000 and 12,000 years ago, the catastrophic floods originating from Glacial Lake Missoula scoured much of the Columbia Basin from the Spokane Valley to Wallula Gap near Walla Walla before following the Columbia River Gorge to the Pacific Ocean. As many as 104 separate catastrophic floods have been documented; these floods scoured the soils and a portion of the bedrock in much of the Columbia Basin before redepositing it in watersheds along the edges of the main flood way. The catastrophic floods deposited the eroded rock and soil materials in the edge basins, like the Walla Walla River watershed. This left behind a history of the flood events and a soil deposit highly susceptible to erosion capped by wind-blown sands, silts, and clays known as loess. The loess deposits are extensive in the southeastern portion of the Columbia Basin.

Landslides in this province include slope failures in bedrock along the soil interbeds and in the overlying catastrophic flood sediments and loess deposits. Bedrock slope failures are most common in the form of very large deep-seated translational landslides and deep-seated slumps or earth flows. A triggering mechanism appears to be over-steepening of a slope or removal of the toe of a slope by streams or the catastrophic glacial floods. These landslides usually move along sediment interbeds within the Columbia River Basalts. Major landslide problems occurred during the relocation of transportation routes required by the filling of the reservoir behind the John Day Dam and in the highly erosive and weak loessal soils of southeastern Washington. Rockfall occurs in the over-steepened rock slopes left behind by the erosion of the catastrophic floods along SR 730 and SR 14.

Irrigation in the Columbia Basin compounds the provinces landslide problems. For example, irrigation near Pasco has increased drainage and landslide problems ten-fold since 1957. Reactivations of relict and dormant deep-seated landslide complexes have occurred in the bluffs along the Columbia River upstream of Richland.

Olympic Mountains

The Olympic Mountains consist of a core of sedimentary rock that has been thrust beneath seafloor basalts, causing uplift of the mountains that continues today. Continental glacial deposits overlay much of the bedrock at lower elevations in the Olympic Mountain province. At higher elevations, the larger drainages were occupied by alpine glaciers. The headwaters of the smaller drainages, however, did not accumulate enough snow to form glaciers. The lower valleys that did not have glaciers have thick sections of weathered soil and bedrock comparable to those in the Southwest Washington landslide province. In these areas, rapid debris flows in steep channels and deep-seated slumps or earth flows are prominent. Adjacent valleys that did have glaciers have soils comparable in age, texture, physical properties and behavior to the sediments in the Puget Lowland.

Recently glaciated valleys that head in the core rocks have landslide problems similar to those in the North Cascades. Debris flows are common throughout the Olympics during intense, prolonged precipitation events and during rain on snow events. Rockfall is also prevalent along the glacially over-steepened bedrock slopes of Lake Crescent on US Highway 101. Slopes composed of older sediments undercut by wave action along the Strait of Juan de Fuca experience extensive deep-seated slumps and earth flows or translational block slides similar to failures discussed in the southern Cascades.

Past Occurrences and Future Probability of Occurrence

Since 1960 Washington State experienced 2 landslides that resulted in Presidential Disaster Declarations, DR-1255 (1988) and DR-4168 (2014). Overall between 1960-2017, there were 285 significant landslides resulting in property damages of almost 2.5 million, and 142 causalities (Source: CEMHS 2018).

Significant Landslide Incidents (1960 2017) (Source: CEMHS 2018)

County	Number of Events	Total Property Damage (Adjusted to 2016)	Injuries	Fatalities
Adams	3	$75,759	0	0
Asotin	1	$33,153	0	0
Benton	2	$69,241	0	0
Chelan	23	$2,178,420	1	0
Clallam	10	$142,221	0	0
Clark	6	$147,490	0	0
Columbia	1	$33,153	0	0
Cowlitz	5	$320,430,556	0	1

Significant Landslide Incidents (1960 2017) (Source: CEMHS 2018)

County	Number of Events	Total Property Damage (Adjusted to 2016)	Injuries	Fatalities
Douglas	3	$45,398	0	0
Ferry	4	$37,685	0	0
Franklin	2	$69,241	0	0
Garfield	1	$33,153	0	0
Grant	3	$75,759	0	0
Grays Harbor	10	$2,766,205	0	1
Island	11	$1,644,563	15	10
Jefferson	11	$543,554	0	0
King	27	$1,376,283,314	0	4
Kitsap	11	$3,360,065	0	4
Kittitas	3	$14,307,649	0	0
Klickitat	2	$69,241	0	0
Lewis	9	$3,890,906	0	1
Lincoln	2	$317,921	0	0
Mason	7	$236,699	0	0
Okanogan	21	$1,150,769	1	0
Pacific	4	$135,552	0	0
Pend Oreille	3	$35,215	0	0
Pierce	13	$5,101,716	0	0
San Juan	3	$74,654	0	0
Skagit	23	$35,389,409	0	3
Skamania	4	$320,369,658	0	1
Snohomish	19	$112,111,827	12	86
Spokane	3	$43,578	0	0
Stevens	3	$36,153	0	0
Thurston	9	$34,291,850	0	0
Wahkiakum	4	$135,552	0	0
Walla Walla	2	$69,241	0	0
Whatcom	8	$1,915,340	0	1
Whitman	2	$69,241	0	0
Yakima	7	$14,360,409	0	0
Washington State	285	$2,252,081,526	30	112

Most of the property damages due to landslides has occurred in King County (61 percent), which also had the highest number of landslide events (27). Between 1960 and 2017, Chelan, Skagit, and Okanogan counties reported the next most events, 23, 23, and 21, respectively (Figure L5). While Snohomish and Cowlitz counties, reporting lower number of landslide events (19 and 5), both accounted for a significant proportion (14 percent) of the total landslide property losses reported in the State.

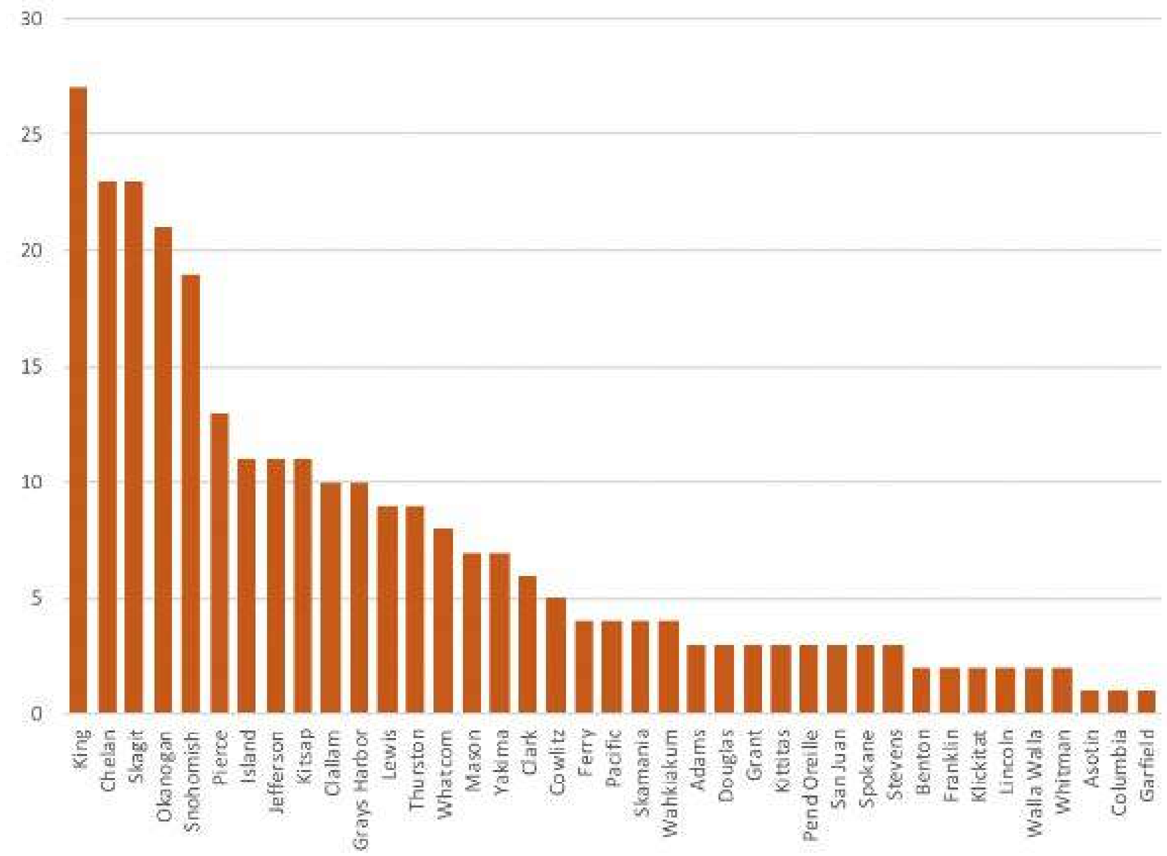


FIGURE L 5: NUMBER OF SIGNIFICANT LANDSLIDE EVENTS (1960-2017)

Since 1960, the state has experienced at least one significant landslide in 25 out of the last 57 years. In 21 of these years, there have been multiple landslide events (2 or more), and in 15 years the state experienced numerous landslides (5 or more). Most landslides in Washington occurred in 1972. Since 2000, the state experienced multiple landslides annually in 14 of the 17 years, with the most happening in year 2014 (24 landslides). Based on the past records since 1960 the likelihood of a major landslide in any given year is 43 percent. The likelihood of multiple (2 or more) landslides in any given year is 32 percent.

Years with at least One Major Landslide Event (1960 2017)	
Year	Total Major Events
1965	40
1972	60
1980	2
1982	3
1983	1

1985	1
1990	4
1991	1
1996	2
1997	3
1998	1
2001	10
2002	2
2003	5
2006	5
2007	8
2008	6
2009	14
2010	6
2011	22
2012	13
2013	18
2014	24
2015	18
2016	16
Grand Total	285

The following is a list of all significant landslide events since 1984. This list is maintained by Washington Geological Survey and can be found on the dnr.wa.gov Landslide Hazard Program page. The list includes tables for both deep landslides and for landslide events, such as large winter storms, where multiple landslides occur.

Landslide Name	Date	Location	Area	Volume	Comments	Fatalities	Direct Costs (millions in 2014 $)	References
SR 530 (*aka* Oso or Hazel)	Mar. 22, 2014	North Fork Stillaguamish River, Snohomish Co.	~262 acres of landslide and debris	Initial estimate 10 million yd^3	Partially dammed river; 49 homes destroyed and 43 lives lost; flooded 0.55 mi^2 of valley; debris field in area of Steelhead Drive is more than 60 ft deep. Severed SR 530 for nearly 2 months. Total impacted area is ~1 mi^2.	43	>80*	Geotechnical Extreme Event Reconnaissance, 2014, The 22 March 2014 Oso landslide, Snohomish County, Washington, p. 186. *Source: Washington State Emergency Management Division
Ledgewood–Bonair (Whidbey Island)	Mar. 27, 2013	Island Co.	12 acres; 900 ft wide; 700 ft long	~200,000 yd^3	Small portion of a larger landslide complex, ~1.5 mi long, ~11,000 years old; 35 homes evacuated when landslide occurred; 20 homes still at risk, either through structural damage or loss of property.	0		Slaughter, Steven; Sarikhan, Isabelle; Polenz, Michael; Walsh, Tim, 2013, Quick report for the Ledgewood–Bonair landslide, Whidbey Island, Island County, Washington: Washington Division of Geology and Earth Resources Quick Report, 7 p. [http://www.dnr.wa.gov/Publications/ger_qr_whidbey_island_landslide_2013.pdf]
Nile Valley (SR 410 MP 108)	Oct. 11, 2009	Yakima Co.	~110 acres	40 million yd^3	Buried one house, severely damaged four others; blocked Naches River and flooded the valley causing significant flood damage to four additional houses; destroyed a 2,500 ft of SR 410. Direct costs for constructing detour route, re-channelizing river and reconstructing the highway.	0	22	WSDOT, 2010, Nile Valley landslide: geotechnical report, May, p. 380. WSDOT, 2010, SR 410 Nile Valley landslide – reconstruct route, December. Cornforth, D. H., 2010, Landslide review and analyses–Nile landslide, Washington: Landslide Technology, 1 v.
Green River Bridge (SR 169 MP 5)	Nov. 2008	King Co.	200 ft long, 200 ft wide		Landslide reactivation threatened south bridge abutment, resulting in multi-month highway closure. Major structural project required to protect south bridge abutment.	0	≈5–10	WSDOT, 2009, Green River Bridge #169/8 – Pier 1 Landslide: geotechnical documentation for FHWA emergency relief, memorandum, 16 p.
Piper Road–Rock Creek	Feb. 2007	Stevenson, Skamania Co.	11 acres; 1,000 ft long; 550 ft wide		The north side of the Columbia River Gorge is one of the most famous landslide provinces in the world. Wet climate, weak bedrock, steep terrain, and a regional dip of 5–30° toward the gorge create ideal conditions for landslides. Landslide occurred within water-saturated clay layers under permeable conglomerate in Eagle Creek Formation.	0		Washington Division of Geology and Earth Resources, 2007, The Rock Creek landslide near Stevenson: DGER News, v. 4, no. 1, p. 1-2. [http://www.dnr.wa.gov/publications/ger_dgernews_2007_v4_no1.pdf]
Rockcrusher Hill (U.S. 101 MP 72.6)	2006	Grays Harbor Co.	1,500 ft long; 400 ft wide	0.5 million yd^3	Ongoing deformation with acceleration in 2006 resulted in costly temporary repair (that has now failed) and now requires frequent repairs to keep highway open. Threatens severing US 101, which would require ~50-mile-long detour. Estimated $7 million repair programmed for 2015.		2	WSDOT, 2007, SR 101 MP 72.6 landslide–geotechnical recommendations, 75 p.
Hazel	2006	North Fork Stillaguamish River, Snohomish Co.	1,000 ft long; 1,000 ft wide	2 million yd^3	Partially dammed river; log revetment constructed to reduce river erosion of landslide toe.	0		Stillaguamish Tribe Natural Resources Department, 2006, Oso slide and North Fork Stillaguamish River avulsion February [http://www.stillaguamish.nsn.us/steelhead%20haven%20slide.htm]
Montesano (SR107 MP 4.7)	Dec. 2005	Grays Harbor Co.	300 ft long, 300 ft wide	100,000 yd^3	Initiated from recent clearcut on previously mapped deep-seated landslide. Severed highway and toed out in Chehalis River. Retaining wall required to stabilize landslide and reopen the highway.	0	≈5	Landslide Technology, 2006, geotechnical report prepared for WSDOT.

Bogachiel (U.S. 101 MP 184)	2004	Jefferson Co.	700 ft long, 2,800 ft wide	1–2 million yd^3	Ongoing deformation within large landslide complex, with failure surface greater than 100 ft deep beneath highway and toeing out in river. Localized acceleration in 2004 resulted in costly repairs for 200-ft-wide section. Movement persists and threatening previous repairs. Evidence for prehistoric catastrophic failures. Threatens severing US 101 with no detour route and no viable mitigation.	0	8	WSDOT, 2007, Bogachiel landslide– geologic assessment and mitigation alternatives, 49 p.
Afternoon Creek (SR 20 MP 121.5)	Nov. 9, 2003	Whatcom Co.	500 ft long, 800 ft wide	1 million yd^3	Rainfall-induced rock slide inundated creek and rockfall debris covered portion of the highway and severely damaged bridge. Cut off access to Diablo residents and upstream Seattle City Light dams. Protection embankment constructed to contain future rockfalls.	0	≈10–15	URS and Wyllie & Norrish, 2004, geotechnical reports prepared for WSDOT
Carlyon Beach	Feb. 6, 1999	Thurston Co.	45 acres; 3,000 ft wide; 900 ft long		Forty one homes and properties were damaged or destroyed. Numerous streets were damaged in Carlyon Beach along with subsurface utilities and overhead power lines. Scarps within the landslide were up to 15 ft in height. Headscarp threatens Hunter Point Road.	0		GeoEngineers, Inc., 1999, Report—Phase II geotechnical study, Carlyon Beach/Hunter Point landslide, Thurston County, Washington: GeoEngineers, Inc. [under contract to] Thurston County Development Services, 1 v.
Jorstad Creek (U.S. 101 MP 322)	Feb. 1999	Mason Co.	500 ft long, 1,000 ft wide	1 million yd^3	Resulted in long duration closure of US 101 with very long detour route. Extensive drainage network required to stabilize slope.	0	≈3	Golder, 1999, Geotechnical report–landslide on U.S. 101 MP 326 Lilliwaup, Washington, prepared for WSDOT.
Lilliwaup U.S. 101 MP 326)	Feb. 1999	Mason Co.	500 ft long, 1,800 ft wide	1.5 million yd^3	Resulted in long duration closure of US 101 with very long detour route. Extensive drainage and retaining wall required to stabilize slope.	0	≈5–10	Golder, 1999, Geotechnical report–landslide on U.S. 101 MP 322, prepared for WSDOT.
Ross Point Complex (SR 166 MP 0.5 to 2.0)	Feb. 1999	Kitsap Co.	300 ft long, 5,000 ft wide		Reactivated landslide complex beginning in 1992 and episodically active through 1999 on approximately mile-long bench above SR 166, resulting in numerous short and long-term closures involving injury accident. Drainage, grading, and rock buttresses required to stabilize landslides.	0	≈15	WSDOT reports and memos
Allyn Curves (SR 3)	Dec. 1998	Mason Co.	2,000 ft long; 1,300 ft wide		Episodically active for decades followed by severe deformation and retrogression in 1997–8 and 1998–99, resulted in 5 month highway closure. Realignment in 1993 and stabilization in 1999 costs totaled around $5 million.	0	≈10–15	WSDOT report and memos
Aldercrest–Banyon	Feb. 1998; Oct. 1998	Cowlitz Co.	3,000 ft long; 1,500$^+$ ft wide		Second costliest landslide disaster in U.S. history involving homes after the Portuguese Bend landslide in southern California; affected 138 homes.	0	110	Wegmann, K. W., compiler, 2004, Geologic field trip to the Aldercrest–Banyon landslide and Mount St. Helens, Washington, Part 1—Stevenson to Castle Rock: Washington Division of Geology and Earth Resources, 24 p. [http://www.dnr.wa.gov/publications/ger_misc_field_trip_stevenson_castle_rock.pdf]

Woodway (Rosary Heights)	Jan. 15, 1997	Snohomish Co.	disrupted a 30,000 m^2 bluff area	100,000 m^3	Pushed five cars of a passing freight train into Puget Sound	0		Arndt, B. P., 1999, Determination of the conditions necessary for slope failure of a deep-seated landslide at Woodway, Washington: Colorado School of Mines Master of Engineering thesis, 216 p.
Maple Hill	Feb. 1996	Skamania Co.	≤1,200 ft across		Severely damaged four homes and rendered them uninhabitable; Loop Road inundated with debris flow generated at the toe of the falling mass; Stewart and View Roads also severely damaged, along with utilities; minor movements began Nov. 1995.	0		Biever, M. P.; Peterson, G. L.; Squier, L. R., 1999, Geotechnical investigation—Maple Hill landslide: Squier Associates, Inc., 1 v.
Morrill Gravel Pit slope failure (U.S. 97A MP 201)	May 19, 1995	Chelan Co.	500 ft long; 1,100 ft wide		Catastrophic mine slope failure killed two people, including young boy, and inundated US 97A.	2	1	Mine Safety and Health Administration, 1995, Investigation of massive slope failure portable crusher no 2, 48 p.
Peters Road (U.S. 12 MP 114)	Nov. 22, 1994	Lewis Co.	2,000 ft long; 500 ft wide	300-500,000 yd^3	Catastrophic debris avalanche buried US 12 in 70,000 yds^3 of debris, effectively isolating the communities of Randle and Packwood from I-5. Major retrogression in 1995. Temporary detour route constructed around landslide runout in 1994; permanent realignment constructed in 1996.	0	≈10–15	Golder, 1995, Geotechnical study–Peters landslide, SR 12, MP 114, prepared for WSDOT, 146 p.
Satus Pass (U.S. 97 MP 28.3)	1992	Yakama Nation	1,000 ft long; 700 ft wide	1.5 million yd^3	Ongoing movement since highway embankment constructed on very large landslide in 1960. Highway was realigned off of the landslide in the late 1990s.	0	≈5	WSDOT, 1993, Satus Pass settlement correction–geotechnical report, 20 p.
KM Mountain	Feb. 10, 1990	Wahkiakum Co.	1,100 ft long; ~800 ft wide	1.5–2 million yd^3	Destroyed 700 ft of SR 4; several mile-long, single-lane detour route required for many months. Stabilization required major regrading and large rock buttress.	0	≈5	Lowell, S. M., 1990, K M Mountain landslide: Washington Geologic Newsletter, v. 18, no. 4, p. 3-7. [http://www.dnr.wa.gov/publications/ger_washington_geology_1990_v18_no4.pdf]
SR 112 MP 36	Feb. 1990	Clallam Co.	1,500 ft long; 500 ft wide		Destroyed approximately 500 ft of highway and toed out in the Straits, resulting in 8 month closure. Highway realigned off of active portion.	0	≈5	WSDOT, 1990 report and memos
Jim Creek (SR112 MP 32)	November 1990	Clallam Co.	300 ft long; 300 ft wide		Destroyed approximately 300 ft of highway and toed out in creek, resulting in 2-month-long highway closure with a very long detour.	0	≈5	WSDOT and Golder reports and memos prepared for WSDOT
Hazel	1988	North Fork Stillaguamish River, Snohomish Co.			Partially dammed river	0		Miller, D. J.; Sias, J. C., 1998, Deciphering large landslides—linking hydrological, groundwater and slope stability models through GIS: Hydrological Processes, v. 12, no. 6, p. 923-941.
Prosser (I-82 MP 92)	1986–1987	Benton Co.			Interstate construction remobilized several very large, prehistoric landslide complexes. Stabilization required alignment revisions, buttresses and grading.	0	≈10–15	WSDOT reports and memos Jamsgard, J. 2013, I-82 Prosser landslide investigation, Benton City, WA technical report, University of Washington master's report, 103 p.

Swift Creek	ongoing	Whatcom			Active, slow-moving landslide deposits more than 100,000 yds^3 of asbestos-laden sediment annually into Swift Creek, raising considerable public health concern and threatening localized flooding of the Nooksack River.	0		McKenzie-Johnson, A. S., 2004, Kinematics of Swift Creek landslide, northwest Washington, Western Washington University master's thesis.
Van Zandt Dike	ongoing	Whatcom			Active landslide	0		Brunengo, M. J., 2001, The Van Zandt Dike landslide, Northwest Geological Society field trip guide, 25 p.
					TOTALS	**45**	**≈$300**	

Widespread Shallow Landslide and Debris Flow Events in Washington State – 1984 to 2014

Time Period	Areas Affected	Description	Fatalities	References
January 2009	western Washington, including Lewis, Skagit, Whatcom, Kittitas, Clark, and Cowlitz Counties	A typical atmospheric river (Pineapple Express) storm rolled through the state, bringing with it warm rains that rapidly melted lowland snow. The Washington Geological Survey reported that the storm caused more than 1,500 landslides greater than 5,000 ft^2 in size. More than 500 landslides were recorded in eastern Lewis County. Approximately 300 to 500 landslides occurred in Skagit and Whatcom Counties.		Sarikhan, I. Y.; Contreras, T. A., 2009, Landslide field trip to Morton, Glenoma, and Randle, Lewis County, Washington: Washington Division of Geology and Earth Resources Open File Report 2009-1, 13 p. [http://www.dnr.wa.gov/publications/ger_ofr2009-1_landslide_field_trip.pdf]
December 2007	western Washington, including Mason, Jefferson, Lewis, and Thurston Counties	The storm event of December 1–3, 2007 caused thousands of landslides and major flooding. The storm brought snow, warm rain, and hurricane force winds across much of western Washington. Landslides blocked or damaged roads, isolating communities in the height of the storm and delaying emergency response. A massive debris avalanche and numerous smaller landslides blocked SR 6. SR 8 was blocked by landslides near Onalaska. Highway 101 was blocked north of the Skokomish River. Nearly 20 in. of rain was recorded within a 48-hour period in the headwaters of the Chehalis River. This caused more than 1,600 landslides in the Chehalis headwater basin alone, clogging flood waters with debris. I-5 was flooded with as much as 10 ft of water.		Sarikhan, I. Y.; Stanton, K. D.; Contreras, T. A.; Polenz, Michael; Powell, Jack; Walsh, T. J.; Logan, R. L., 2008, Landslide reconnaissance following the storm event of December 1-3, 2007, in western Washington: Washington Division of Geology and Earth Resources Open File Report 2008-5, 16 p. [http://www.dnr.wa.gov/publications/ger_ofr2008-5_dec2007_landslides.pdf]
December 2006	western Washington	A strong storm known as the Hanukkah Eve Storm of 2006 brought hurricane force wind gusts and heavy rains to western Washington. The storm initiated a small number of landslides around western Washington.		
January to February 2006	entire state	Prolonged heavy rainfall from December 2005 into January 2006 caused numerous landslides throughout the state. More than 13 in. of rain fell between December 19 and January 14. Slides, slumps, or settlement closed lanes of I-5, US 101, SR's 4, 9, 14, 107, 105, 112, 116, 166, 302, and 530 for various periods. On February 3, the Governor signed emergency proclamation requesting federal funds for all 39 counties.		Information from news reports and the Washington Department of Transportation
October 2003	entire state, including Skagit, Okanogan, Clallam, Jefferson, Mason, Snohomish, Pierce Counties	Heavy rainfall caused severe flooding and landslides in 15 counties. Landslides or ground failure caused temporary closures on nine state highways. Landslides closed SR 20 between Skagit and Okanogan Counties, a landslide closed SR 112 in Clallam County, debris flows also blocked US 101 in Jefferson and Mason Counties, US 2 in Snohomish County, and SR 410 in Pierce County.		
Nisqually Earthquake – February 28, 2001	western Washington, including Tacoma, Renton, Olympia, Burien, and Tumwater	The magnitude 6.8 earthquake produced a number of significant, widely scattered landslides resulting in at least $34.3 million in losses. Salmon Beach suffered a 1,300 yd^3 landslide that demolished two homes. Cedar River had two landslides, one of which was an estimated 50,000 yd^3. The parkway on Capitol Lake experienced significant damage from ground failure. Five homes in Burien sustained structural damage when underlying fill formed a landslide.		Highland, L. M., 2003, An account of preliminary landslide damage and losses resulting from the February 28, 2001, Nisqually, Washington, earthquake: U.S. Geological Survey Open-File Report 03-211, 48 p. [http://pubs.usgs.gov/of/2003/ofr-03-211/ofr-03-211.pdf]

September 17, 1997	Clallam Co.	Debris flow-avalanche kills one in Port Angeles tavern situated below steep slope. Weather was not especially wet preceding the event (0.5 in. of rain).	1	
December 1996 to January 1997	western Washington, primarily the bluffs of Puget Sound, Lake Washington, Lake Union, Portage Bay, West Seattle, Magnolia Bluff, and along the I-5 corridor	December precipitation was 191% of normal, triggering hundreds of landslides and debris flows on steep bluffs and ravines. At least four people were killed by these events, and millions of dollars of damage were caused. A landslide on January 15 derailed five cars of a freight train midway between Seattle and Everett. Twenty to 30 landslides occurred in Pierce County, including one that cut phone service to homes on Salmon Beach. In Whatcom and Clark Counties, two interstate natural gas lines were ruptured due to landslides, causing explosions, fires, and evacuations.	4	Gerstel, W. J.; Brunengo, M. J.; Lingley, W. S., Jr.; Logan, R. L.; Shipman, Hugh; Walsh, T. J., 1997, Puget Sound bluffs—The where, why, and when of landslides following the holiday 1996/97 storms: Washington Geology, v. 25, no. 1, p. 17-31. [http://www.dnr.wa.gov/publications/ger_washington_geology_1997_v25_no1.pdf] Baum, R. L.; Chleborad, A. F.; Schuster, R. L., 1998, Landslides triggered by the winter 1996-97 storms in the Puget Lowland, Washington: U.S. Geological Survey Open-File Report 98-239, 16 p., 1 plate. [http://pubs.usgs.gov/of/1998/ofr-98-239/]
February 1996	entire state, including Walla Walla, Seattle, and Pierce, Thurston, Lewis, Clark, and Skamania Counties	Near-record snowfall in January followed by warm, heavy rain caused massive flooding and landslides. Landslides damaged or destroyed nearly 8,000 homes and closed traffic along major highways (including I-5, SR 4, and SR 503) for several days. Damages totaled at least $800 million. The highest concentration of landslides occurred near Walla Walla. Seattle had more than 40 landslides during the winter, about two-thirds of which were related to the storm. Lewis County had the largest landslide, with an estimated 1.5 million yd^3 of debris.		U.S. Federal Emergency Management Agency, 1996, Interagency Hazard Mitigation Team report, including progress report on early implementation strategies—State of Washington, winter storms of 1995-1996; FEMA-DR-1079, declared January 3, 1996; FEMA-DR-1100-WA, declared February 9, 1996: U.S. Federal Emergency Management Agency, 88 p. Harp, E. L.; Chleborad, A. F.; Schuster, R. L.; Cannon, S. H.; Reid, M. E.; Wilson, R. C., 1998, Landslides and landslide hazards in Washington State due to February 5-9, 1996 storm: U.S. Geological Survey Administrative Report, 1 v. [http://www.preventionweb.net/files/1585_Washhrp.pdf]
November 2, 1985	Skagit Co.	Marblemount debris flow	4	
		TOTAL	**9**	

Relationship to Other Hazards

Landslides can be triggered by strong ground motions. Earthquakes and volcanoes contribute significantly to the landslide hazards (Alexander 1992). Ground shaking creates stresses that make weak slopes fail. Earthquakes of magnitude 4.0 and greater have been known to trigger landslides (Keefer 1984).

Landslides triggered by earthquake shaking are a major concern in the Pacific Northwest. Earthquake Point near Entiat in Chelan County, is named after the ~ M7 1872 earthquake that struck nearby. The shaking split the mountain, forming the cliff to the west and causing a huge rockslide which stopped the flow of the Columbia River for several hours.

Heavy rainfalls can also cause significant landslides, which in turn can result in flooding. Heavy rainfalls can saturate the ground, greatly increasing pore pressures, particularly where porous soil layers meet less permeable soils such as clay, and then move out along that boundary toward an open face or bluff (Wang and Sassa 2003). Slope material that becomes saturated with water may develop a debris flow or mud flow. The resulting slurry of rock and mud may pick up trees, houses, and cars, thus blocking bridges and tributaries causing flooding along its path.

Volcanic eruptions can produce lahars, also known as volcanic mudflows. These flows originate on the slopes of volcanoes, mobilize the loose accumulations of tephra (the airborne solids erupted from the volcano), earth material and debris along the flow channels. These volcanic landslides tend to be much larger and have a higher flow rate than the non-volcanic landslides (Seibert 2002).

Intense surface-water flow, due to heavy precipitation or rapid snowmelt, can erode and mobilize loose soil or rock on steep slopes causing debris flows. Debris flows can also result from other types of landslides that occur on steep slopes. These flows are nearly saturated and consist of a large proportion of silt- and sand-sized material. Debris flows can be particularly lethal because of their rapid onset, high speed of movement, and dislodging of large boulders and other debris (Iverson et. al. 1997). Such flows can move objects as large as houses in their downslope flow or can fill structures with a rapid accumulation of sediment and organic matter.

Wildfires, which clear slopes of vegetation, can lead to debris flows. Following recent wildfires in Washington, affected communities have experienced large increases in flash flooding that damaged irrigation systems and destroyed roads. The City of Montecito, California, following record wildfires in the fall of 2017, experienced debris flows in early 2018 that nearly destroyed several neighborhoods (Antczak 2018). Climate change is increasing the risk of wildland fires and resulting soil mobilization including landslides.

Landslide Risk Assessment

Landslide hazard is estimated based on the digital version of the ??? Geological Survey Professional Paper 1183, Landslide Overview Map of the Conterminous United States (Radbruch-Hall et al. 1982). This map delineates areas where large numbers of landslides have occurred and areas which are susceptible to landslides in the conterminous United States. In compiling this dataset, the authors defined landslides as ‘any downward or outward movement of earth materials on a slope’. This assessment did not include talus deposits, deposits resulting from ancient landslides not related to present slopes, large gravitational thrust sheets, solifluction deposits, snow avalanches, and debris deposited by flows that contribute to alluvial fans in arid regions. The data set also provides a limited assessment of susceptibility to landslides which is defined as the probable degree of response of the areal rocks and soils to natural or artificial cutting or loading of slopes or to anomalously high precipitation. However, for the purpose of this risk assessment, susceptibility categories were ignored because the authors indicate possibility of greater uncertainty and subjectivity in susceptibility assessments due to insufficient data.

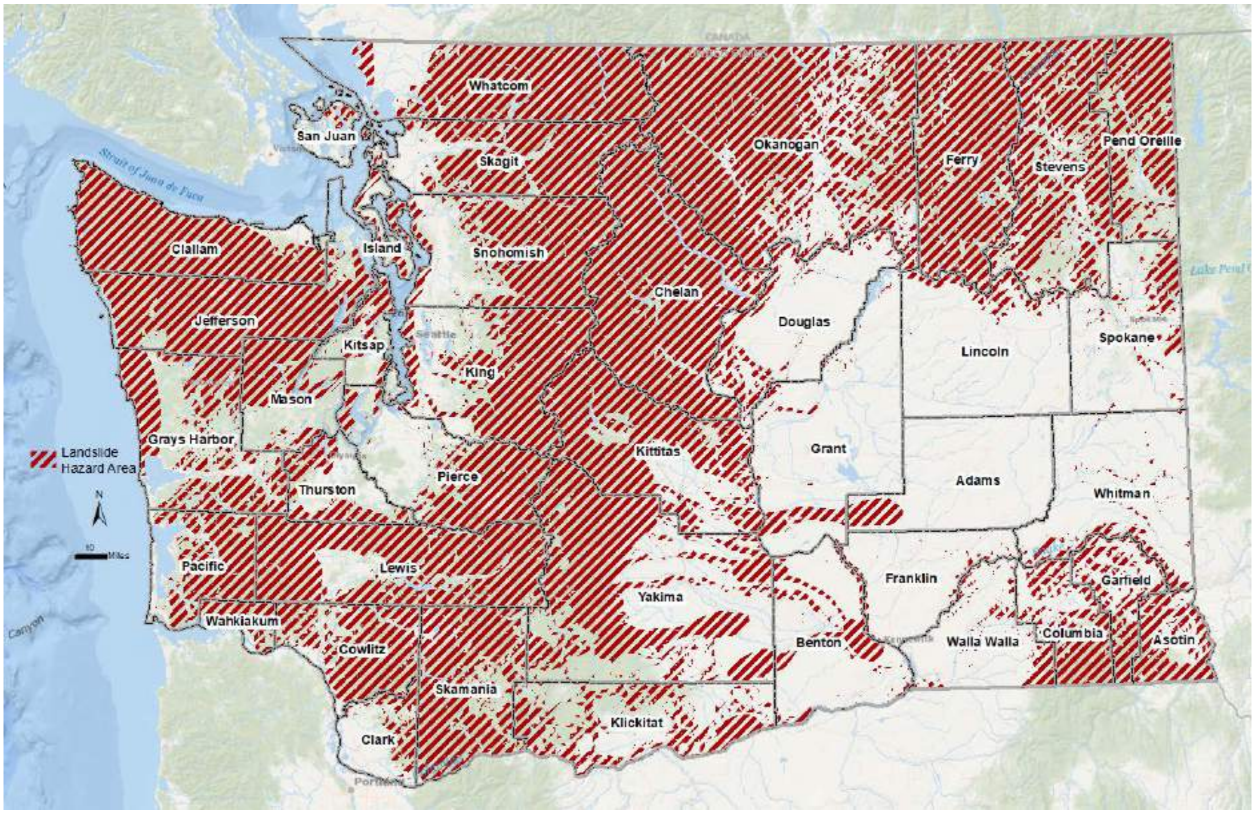


FIGURE L 8: LANDSLIDE HAZARD AREAS (RADBRUCH-HALL ET AL. 1982)

Area Exposure

The landslide hazard area map was overlaid with the state's county map to estimate the percentage area exposed to landslide hazard in each county. Almost 55 percent of the total land area of the state is estimated to have some level of risk from landslides. Counties with steeper slopes and higher than average precipitation have a higher likelihood of landslides. In Chelan and Clallam counties more than 90 percent of the land area is exposed to landslide hazards. In Ferry, Lewis, Jefferson, Skamania, Okanogan, Cowlitz, and Wahkiakum counties more than 75 percent of the land area is exposed to landslide hazards. Grant, Lincoln, Adams, and Franklin counties have the lowest landslides hazard exposure with less than 10 percent of county area in landslide hazard zones.

Percentage of County Land Area with Landslide Hazard Exposure	
County	Percent Area
Adams	7.02
Asotin	69.89
Benton	20.26
Chelan	93.55
Clallam	91.92
Clark	28.28
Columbia	64.20
Cowlitz	76.02
Douglas	19.73
Ferry	88.51
Franklin	6.58
Garfield	57.66
Grant	7.55
Grays Harbor	51.20
Island	40.60
Jefferson	79.72
King	62.41
Kitsap	37.28
Kittitas	72.14
Klickitat	38.05
Lewis	82.49
Lincoln	7.16
Mason	49.09
Okanogan	76.84
Pacific	60.55
Pend Oreille	70.84
Pierce	50.65
San Juan	14.98
Skagit	72.73
Skamania	79.07
Snohomish	64.64
Spokane	16.11
Stevens	67.56

Percentage of County Land Area with Landslide Hazard Exposure	
County	Percent Area
Thurston	41.85
Wahkiakum	76.01
Walla Walla	14.56
Whatcom	69.51
Whitman	10.14
Yakima	54.60
Washington State	54.06

Population Exposure

Assessing landslide exposure for populations is difficult due to the lack of accurate data. Data on landslide coverage is rough and inexact in many counties, while data for population location can be misleading. Population numbers used here should not be considered as exact measures of total people exposed to natural hazards in each county.

Population exposure to landslides was estimated by laying landslide hazard data over developed areas derived from the 2011 land cover database. The 2017 estimated population for all census tracts was allocated to respective urban areas and the overlap with landslide exposure was estimated using spatial analysis in Geographic Information System (GIS). While almost 55 percent of the area of the state is exposed to landslides, the population exposure is estimated to be less than 25 percent of the state population. More than 50 percent of the population in Adams, Skamania, Lewis, Benton, Garfield, Jefferson, Klickitat, and Wahkiakum counties resides in areas that may be exposed to landslides. King County has the largest population (575,000 persons) residing in areas exposed to landslides. More than 100,000 residents in Benton, Kitsap and Snohomish counties may also be exposed to landslide hazards.

Population Exposure to Landslides			
County	Total Population (2017 Estimates)	Percentage of Total State Population	Estimated Population Exposure to Landslides (in % values)
Adams	19870	0.27	97.20
Asotin	22290	0.30	4.60
Benton	193500	2.65	65.29
Chelan	76830	1.05	19.63
Clallam	74240	1.02	44.97
Clark	471000	6.44	1.34
Columbia	4100	0.06	13.30
Cowlitz	105900	1.45	23.00
Douglas	41420	0.57	17.45
Ferry	7740	0.11	17.37
Franklin	90330	1.24	19.48
Garfield	2200	0.03	62.21
Grant	95630	1.31	2.97
Grays Harbor	72970	1.00	27.75

Population Exposure to Landslides			
County	Total Population (2017 Estimates)	Percentage of Total State Population	Estimated Population Exposure to Landslides (in % values)
Island	82790	1.13	45.56
Jefferson	31360	0.43	56.26
King	2153700	29.46	26.67
Kitsap	264300	3.62	44.52
Kittitas	44730	0.61	0.00
Klickitat	21660	0.30	56.01
Lewis	77440	1.06	68.07
Lincoln	10700	0.15	0.00
Mason	63190	0.86	27.49
Okanogan	42110	0.58	14.26
Pacific	21250	0.29	44.51
Pend Oreille	13370	0.18	0.00
Pierce	859400	11.76	6.28
San Juan	16510	0.23	1.18
Skagit	124100	1.70	1.82
Skamania	11690	0.16	79.55
Snohomish	789400	10.80	13.03
Spokane	499800	6.84	0.77
Stevens	44510	0.61	9.84
Thurston	276900	3.79	26.09
Wahkiakum	4030	0.06	50.53
Walla Walla	61400	0.84	0.05
Whatcom	216300	2.96	16.53
Whitman	48640	0.67	8.55
Yakima	253000	3.46	4.98
Washington State	7310300	100.00	21.50

Vulnerable Population Exposure

The social vulnerability index was created for each of the census tracts using American Community Survey (ACS) 2011-2016 5-year data. Social vulnerability data was first overlaid with developed areas extracted from the 2011 land cover database. Tract level social vulnerability estimates were assigned to respective developed areas in each of the tracts. This data was then overlaid with landslide hazard layer to identify socially vulnerable developed areas that overlap with landslide exposure.

Overall, only 6 percent of the total state population is both, ranked medium or higher on social vulnerability and resides in areas exposed to landslides. In Adams and Grant counties, all of the population exposed to landslide risk is also ranked medium or higher on social vulnerability. In Douglas and Yakima counties, more than 50 percent of the county population exposed to landslides is also ranked medium or higher on social vulnerability. King County has the highest number of socially vulnerable population residing in areas exposed to landslides. However, this constitutes less than 10 percent of the total population exposed to landslides in King County.

Vulnerable Population Exposure to Landslides			
County	Population Exposed to Landslides		
	Population (2017 Estimates)	Vulnerable Population	Vulnerable Population (%)
Adams	19313	19313	100.00
Asotin	1025	0	0.00
Benton	126343	7379	5.84
Chelan	15082	0	0.00
Clallam	33382	970	2.91
Clark	6331	0	0.00
Columbia	545	0	0.00
Cowlitz	24353	2	0.01
Douglas	7226	5144	71.19
Ferry	1345	0	0.00
Franklin	17598	532	3.02
Garfield	1369	0	0.00
Grant	2842	2831	100.00
Grays Harbor	20251	1987	9.81
Island	37719	0	0.00
Jefferson	17643	0	0.00
King	574387	45220	7.87
Kitsap	117654	0	0.00
Kittitas	0	0	0.00
Klickitat	12132	0	0.00
Lewis	52716	900	1.71
Lincoln	0	0	0.00
Mason	17374	195	1.12
Okanogan	6003	2242	37.35
Pacific	9458	0	0.00
Pend Oreille	0	0	0.00
Pierce	53981	280	0.52
San Juan	194	0	0.00
Skagit	2263	0	0.00
Skamania	9299	0	0.00
Snohomish	102887	16	0.02
Spokane	3873	0	0.00
Stevens	4382	61	1.39
Thurston	72237	1843	2.55

Vulnerable Population Exposure to Landslides			
County	Population Exposed to Landslides		
	Population (2017 Estimates)	Vulnerable Population	Vulnerable Population (%)
Wahkiakum	2036	0	0.00
Walla Walla	28	0	0.00
Whatcom	35759	0	0.00
Whitman	4158	0	0.00
Yakima	12606	7573	60.07
Washington State	1572075	92030	5.85

Built Environment Exposure

The built environment exposure to landslide hazard is calculated using the general building stock data (2014) provided by FEMA that contains the building values for all structures in the census tracts. General building stock values used in this analysis are the total structure value of all buildings (except agricultural) in each census tract in 2014 dollars. Building values for all occupancy types were summed for each census tract using only structure values (not content values) and assigned to the developed areas within each tract. These maps were then overlaid on the landslide hazard layer to estimate the general building stock value within landslide exposure areas. Individual tract level estimates were aggregated to create the county level estimates.

Overall, 22 percent of the general building stock of the state is in areas exposed to landslides. King County has highest value of general building stock value in areas at risk from landslides. In Adams, Skamania, Lewis, Benton, Jefferson, Klickitat, and Wahkiakum counties more than 50 percent of the general building stock is in areas exposed to landslides. In Stevens, Whitman, Pierce, Yakima, Asotin, Grant, Skagit, Garfield, Clark, and San Juan counties less than 10 percent of the county general building stock is exposed to landslide hazard.

Built Environment Exposure to Landslides			
County	Total Value of General Building Stock (2014)	**Exposed to Landslides**	
		Total Value of General Building Stock (2014)	Percent of Total GBS
Adams	$253,615	$246,512	97.20
Asotin	$1,061,235	$48,823	4.60
Benton	$6,529,565	$4,264,430	65.31
Chelan	$1,573,417	$308,878	19.63
Clallam	$2,427,219	$1,090,722	44.94
Clark	$32,074,170	$430,371	1.34
Columbia	$533	$71	13.30
Cowlitz	$4,992,730	$1,145,023	22.93
Douglas	$1,211,949	$211,432	17.45
Ferry	$1,521	$264	17.37

Built Environment Exposure to Landslides			
County	Total Value of General Building Stock (2014)	Exposed to Landslides	
		Total Value of General Building Stock (2014)	Percent of Total GBS
Franklin	$1,867,499	$363,119	19.44
Garfield	$437	$7	1.51
Grant	$583,022	$17,325	2.97
Grays Harbor	$1,162,104	$322,446	27.75
Island	$2,895,464	$1,303,258	45.01
Jefferson	$1,137,144	$639,757	56.26
King	$362,698,022	$96,663,009	26.65
Kitsap	$17,267,166	$7,686,189	44.51
Kittitas	$530,126	$0	0.00
Klickitat	$4,479	$2,511	56.05
Lewis	$1,402,914	$955,829	68.13
Lincoln	$87,198	$0	0.00
Mason	$608,531	$167,311	27.49
Okanogan	$59,252	$8,447	14.26
Pacific	$125,715	$55,978	44.53
Pend Oreille	$8,310	$0	0.00
Pierce	$62,547,883	$3,920,953	6.27
San Juan	$225,856	$2,658	1.18
Skagit	$5,389,339	$98,382	1.83
Skamania	$17,391	$13,888	79.86
Snohomish	$52,406,666	$6,818,775	13.01
Spokane	$31,281,088	$242,370	0.77
Stevens	$325,218	$32,017	9.84
Thurston	$9,798,392	$2,554,263	26.07
Wahkiakum	$1,649	$833	50.53
Walla Walla	$3,061,065	$1,394	0.05
Whatcom	$15,241,051	$2,512,750	16.49
Whitman	$1,385,430	$119,258	8.61
Yakima	$7,986,979	$397,948	4.98
Washington State	$630,231,344	$135,415,924	21.49

Critical Infrastructure Exposure

Critical infrastructure facilities within the landslide hazard areas are likely to be directly impacted by landslides. While the nature and degree of impact will largely depend on the size of the landslide and the physical details of the facility, location within the landslide hazard area can enable prioritization of site-specific hazard mitigation studies. Location of 12 critical infrastructure facility types including airports (23), communication towers (16097), dams (268), education facilities (5331), electric substations (1392), hospitals (147), power plants (146), public transit stations (60), railroad bridges (1619), railway stations (317), urgent care facilities (113), and weather radar stations (2), were derived from the Homeland Security Foundation Level Database (HIFLD). This data was overlaid with the landslide hazard exposure layer to identify facilities located in landslide areas. This analysis refers to point data and not critical infrastructure represented by a line such as roads and rail corridors. Most of the State's major transportation corridors include segments that are exposed to active landslide areas. An overall assessment of transportation corridors is included in the state summary section of the report.

Spatial analysis of this dataset reveals that 42 percent of critical infrastructure facilities in the state are located in areas exposed to landslides. King County has the maximum number of critical infrastructure facilities (1221) located in areas at risk from landslides. In Skamania, Ferry, and Lewis counties more than 80 percent of the county critical infrastructure facilities are in areas exposed to landslides. In several counties including, Jefferson, Kitsap, Pacific, Klickitat, Stevens, Okanogan, Chelan, Kittitas, Benton, Clallam, Thurston, and Whitman more than 50 percent of critical infrastructure facilities are in areas exposed to landslides. While this represents a significant amount of landslide risk to critical infrastructure in these counties, it is important to note that this assessment reflects generalized risk from landslides. Specific risk to each facility results from the combination of the event characteristics (which are difficult to predict) and site-level facility characteristics.

Critical Infrastructure Exposure

County	Number of Critical Infrastructure Facilities	In Landslide Exposure Areas	
		Number of Critical Infrastructure Facilities	Percent of Critical Infrastructure Facilities
Adams	206	44	21.36
Asotin	81	26	32.10
Benton	664	382	57.53
Chelan	507	305	60.16
Clallam	273	151	55.31
Clark	490	84	17.14
Columbia	88	24	27.27
Cowlitz	474	202	42.62
Douglas	290	83	28.62
Ferry	83	73	87.95
Franklin	270	29	10.74
Garfield	89	12	13.48
Grant	501	133	26.55
Grays Harbor	377	153	40.58
Island	104	42	40.38
Jefferson	197	143	72.59
King	2761	1221	44.22
Kitsap	451	299	66.30
Kittitas	303	175	57.76
Klickitat	322	207	64.29
Lewis	374	313	83.69

Critical Infrastructure Exposure			
County	Number of Critical Infrastructure Facilities	In Landslide Exposure Areas	
		Number of Critical Infrastructure Facilities	Percent of Critical Infrastructure Facilities
Lincoln	237	26	10.97
Mason	152	73	48.03
Okanogan	359	217	60.45
Pacific	152	98	64.47
Pend Oreille	69	32	46.38
Pierce	1130	166	14.69
San Juan	98	11	11.22
Skagit	474	173	36.50
Skamania	145	133	91.72
Snohomish	787	209	26.56
Spokane	933	261	27.97
Stevens	211	132	62.56
Thurston	462	239	51.73
Wahkiakum	17	5	29.41
Walla Walla	273	36	13.19
Whatcom	613	302	49.27
Whitman	409	209	51.10
Yakima	601	244	40.60
Washington State	16027	**6667**	41.60

State Operations and Facilities Exposure

The list of state owned (9415) and leased facilities (1039) was obtained from 2017 Facilities Inventory System Report produced by Office of Financial Management (detailed list included in Appendix I-2). These facilities were geo-located based on the addresses provided in the facilities inventory report and then overlaid with landslide hazard layer.

The spatial analysis reveals that 26 percent of state-owned facilities are in areas with landslide exposure. In all counties, at least 20 percent of the facilities are in areas at risk from landslides. More than 40 percent of the state-owned facilities in Ferry County are in areas threatened by landslides. In Klickitat, Skamania, Columbia, Whatcom, Okanogan, Wahkiakum, Lincoln, Island, and Cowlitz counties 30-35 percent of the state-owned facilities in the county are in areas exposed to landslides.

Overall, almost 25 percent of the state-leased facilities are also in areas threatened by landslides. In Adams and Columbia counties, the lone state-leased facilities are located in areas with landslide exposure. Thurston County has the maximum number (93) of state-leased facilities in areas exposed to landslides. In King County, 74 of the state-leased facilities are in areas exposed to landslides; these constitute 33 percent of the state-leased facilities in the County. None of the state-leased facilities in Asotin, Chelan, Clark, Ferry, Franklin, Garfield, Island, Jefferson, Kittitas, Lincoln, Mason, Okanogan, Pacific, Pend Oreille, Pierce, Skagit, Wahkiakum, and Walla Walla counties are in areas threatened by landslides.

State Owned and Leased Facilities Exposure

County	State Owned Facilities	State Leased Facilities	In areas Exposed to Landslides			
			State Owned Facilities	Percent of State Owned Facilities	State Leased Facilities	Percent of State Leased Facilities
Adams	64	1	17	26.56	1	100.00
Asotin	90	6	25	27.78	0	0.00
Benton	159	30	40	25.16	29	96.67
Chelan	192	22	48	25.00	0	0.00
Clallam	183	12	47	25.68	2	16.67
Clark	229	23	66	28.82	0	0.00
Columbia	75	1	25	33.33	1	100.00
Cowlitz	128	18	39	30.47	5	27.78
Douglas	42	10	12	28.57	1	10.00
Ferry	32	3	13	40.63	0	0.00
Franklin	160	9	38	23.75	0	0.00
Garfield	21	0	5	23.81	0	0.00
Grant	252	15	57	22.62	1	6.67
Grays Harbor	224	13	58	25.89	2	15.38
Island	269	6	82	30.48	0	0.00
Jefferson	394	5	116	29.44	0	0.00
King	1120	226	275	24.55	74	32.74
Kitsap	269	15	77	28.62	9	60.00
Kittitas	348	11	69	19.83	0	0.00
Klickitat	110	10	38	34.55	4	40.00
Lewis	163	13	37	22.70	12	92.31
Lincoln	58	0	18	31.03	0	0.00
Mason	244	7	70	28.69	0	0.00
Okanogan	179	10	58	32.40	0	0.00
Pacific	233	6	68	29.18	0	0.00
Pend Oreille	18	5	5	27.78	0	0.00
Pierce	865	54	215	24.86	0	0.00
San Juan	282	5	81	28.72	1	20.00
Skagit	286	15	85	29.72	0	0.00
Skamania	64	2	22	34.38	2	100.00
Snohomish	270	71	74	27.41	12	16.90
Spokane	571	121	124	21.72	1	0.83

State Owned and Leased Facilities Exposure						
County	State Owned Facilities	State Leased Facilities	In areas Exposed to Landslides			
			State Owned Facilities	Percent of State Owned Facilities	State Leased Facilities	Percent of State Leased Facilities
Thurston	431	166	117	27.15	93	56.02
Walla Walla	159	11	41	25.79	0	0.00
Whitman	566	9	133	23.50	2	22.22
Washington State	9415	1031	**2466**	26.19	**255**	24.73

First Responder Facilities Exposure

Locations of fire stations, law enforcement buildings, and emergency medical stations in the state were identified from the Homeland Security Foundation Level Database (HIFLD). Using ESRI ArcMap geocoding services, 1,268 fire stations, 332 law enforcement agencies, and 1,162 EMS stations (including those co-located with fire stations) were located on the state map. It is estimated 23 percent of the fire stations, 68 percent of the law enforcement buildings, and 23 percent of the EMS facilities are in areas exposed to landslides. In Garfield County, all fire stations (2), law enforcement buildings (1), and EMS facilities (1) are in areas exposed to landslides. In King County, 40 fire stations, 19 law enforcement buildings, and 40 EMS facilities are in areas exposed to landslides. In Adams County, where all of the urban area is at risk from landslides, 18 percent of fire stations, and 50 percent of law enforcement buildings are in areas exposed to landslides. None of five EMS facilities in the county are in landslide risk areas.

First Responder Facilities Exposure to Landslides									
County	Fire Station			Law Enforcement			EMS		
	Total Number of Facilities	In areas Exposed to Landslide		Total Number of Facilities	In areas Exposed to Landslides		Total Number of Facilities	In areas Exposed to Landslides	
		Number of facilities	Percent Facilities		Number of facilities	Percent Facilities		Number of facilities	Percent Facilities
Adams	11	2	18.18	4	2	50.00	5	0	0.00
Asotin	3	1	33.33	4	0	0.00	2	0	0.00
Benton	29	14	48.28	7	4	57.14	27	15	55.56
Chelan	30	8	26.67	3	0	0.00	21	8	38.10
Clallam	22	12	54.55	5	1	20.00	24	13	54.17
Clark	40	1	2.50	13	0	0.00	40	1	2.50
Columbia	3	0	0.00	1	0	0.00	2	0	0.00

First Responder Facilities Exposure to Landslides

County	Fire Station			Law Enforcement			EMS		
	Total Number of Facilities	In areas Exposed to Landslide		Total Number of Facilities	In areas Exposed to Landslides		Total Number of Facilities	In areas Exposed to Landslides	
		Number of facilities	Percent Facilities		Number of facilities	Percent Facilities		Number of facilities	Percent Facilities
Cowlitz	25	5	20.00	8	0	0.00	17	3	17.65
Douglas	12	1	8.33	3	1	33.33	8	0	0.00
Ferry	12	4	33.33	3	1	33.33	5	2	40.00
Franklin	20	1	5.00	7	0	0.00	15	1	6.67
Garfield	2	2	100.00	1	1	100.00	1	1	100.00
Grant	50	4	8.00	15	1	6.67	28	2	7.14
Grays Harbor	32	9	28.13	9	1	11.11	20	6	30.00
Island	10	5	50.00	4	0	0.00	9	5	55.56
Jefferson	12	5	41.67	4	2	50.00	13	5	38.46
King	159	40	25.16	60	19	31.67	161	40	24.84
Kitsap	47	23	48.94	6	3	50.00	49	24	48.98
Kittitas	33	5	15.15	6	0	0.00	33	5	15.15
Klickitat	36	10	27.78	3	1	33.33	25	6	24.00
Lewis	51	22	43.14	12	7	58.33	50	24	48.00
Lincoln	10	1	10.00	4	0	0.00	9	1	11.11
Mason	46	16	34.78	3	0	0.00	47	16	34.04
Okanogan	27	7	25.93	7	0	0.00	17	4	23.53
Pacific	16	1	6.25	5	0	0.00	10	0	0.00
Pend Oreille	18	2	11.11	1	0	0.00	16	2	12.50
Pierce	99	15	15.15	29	1	3.45	101	16	15.84
San Juan	4	0	0.00	1	0	0.00	5	0	0.00
Skagit	39	3	7.69	6	0	0.00	40	4	10.00
Skamania	3	2	66.67	2	2	100.00	3	2	66.67
Snohomish	74	15	20.27	23	4	17.39	73	14	19.18
Spokane	52	3	5.77	10	0	0.00	50	3	6.00
Stevens	34	11	32.35	6	1	16.67	27	5	18.52
Thurston	47	18	38.30	17	11	64.71	55	20	36.36
Wahkiakum	9	3	33.33	1	0	0.00	5	3	60.00
Walla Walla	21	1	4.76	3	0	0.00	20	1	5.00
Whatcom	50	13	26.00	10	2	20.00	54	12	22.22
Whitman	24	3	12.50	8	2	25.00	22	3	13.64
Yakima	56	8	14.29	18	1	5.56	53	6	11.32
Washington State	1268	296	23.34	332	68	20.48	1162	273	23.49

Washington State Risk Index for Landslides (WaSRI-L)

The landslide risk index (WaSRI-L) for each county is estimated as the average of the standardized rank of landslide exposure assessment for population, vulnerable populations, built environment, critical infrastructure facilities, state facilities and first responder facilities. The individual exposure assessment values were categorized into 5 classes (1: Low, 2: Medium-Low, 3: Medium, 4: Medium-High, and 5: High) using z-score transformation (standard deviations from the mean).

Classification Schema for Standardized Exposure Assessment Values	
Standard Deviation	Classification Rank
>1	High (5)
0.50 to 1.0	Medium-High (4)
0.5 to -0.5	Medium (3)
-0.5 to -1	Medium-Low (2)
< -1.0	Low (1)

The landslide risk index (WaSRI-L) is the mean of these individual exposure rankings. While similar assessments were also done for economic consequences and risk to environment (described in the next sections), specific rankings were not included in the estimation of the landslide risk index. Economic consequence rankings were not included because of data quality limitations that were likely to result in biased estimation of landslide risk. The natural environment assessment includes a limited number of environmental resources. Each natural hazard is associate with specific effects on the natural environment and therefore adoption of a common evaluation approach across all hazard types for environmental impacts is not appropriate.

The statistical analysis of landslide exposure assessments reveals that five counties – Benton, Clallam, Jefferson, Lewis, and Skamania are at the highest risk from landslides. All of these counties have high proportion of residents located in areas exposed to landslides. While the proportion of county area at risk from landslides is among the lowest for Benton County, it has significant proportion (medium or higher) of county population, vulnerable population, built environment, critical infrastructure, state facilities, and first responder facilities situated in landslide areas.

In contrast, while Chelan County has a high proportion of county area with landslide exposure, the overall landslide risk is low because of lower than medium exposure of vulnerable population and state facilities. The proportion of population, built environment, and first responder facilities to landslide is also estimated to be medium in Chelan County.

Clark, Lincoln, Pend Oreille, Pierce, San Juan, Spokane, Walla Walla, and Whitman counties are estimated to have low landslide risk. While Pend Oreille County has a significant land, area exposed to landslides (ranked medium-high), the overall landslide risk to this county is low due to low exposure to landslides for all other factors.

A number of counties - Adams, Ferry, Island, Kitsap, Klickitat, Okanogan, Thurston, and Wahkiakum, are ranked medium-high on landslide risk index. Among these, Adams, Island, Kitsap, and Klickitat counties have lower than medium land area exposure to landslides but are still at higher risk from landslides due to higher rank for other landslide exposure elements.

King County is estimated to be at medium risk from landslides even though it has the highest number of persons (though it is a small proportion of its population) residing in areas exposed to landslides.

Landslide Risk Index (WaSRI L) and Constituent Landslide Exposure Ranks for Each County

County	Area	Population	Vulnerable Population	Built Environment	Critical Infrastructure	State Facilities	First Responder Facilities	Landslide Risk Index (WaSRI L)
Adams	Low	High	High	High	Medium-Low	Medium	Medium-Low	Medium-High
Asotin	Medium-High	Medium-Low	Low	Low	Medium	Medium	High	Medium
Benton	Low	High	Medium	High	Medium-High	High	High	High
Chelan	High	Medium	Low	Medium	Medium-High	Medium-Low	Medium	Medium
Clallam	High	Medium-High	Medium-Low	Medium-High	Medium-High	Medium	High	High
Clark	Medium-Low	Medium-Low	Low	Low	Low	Medium	Low	Low
Columbia	Medium	Medium	Low	Medium-Low	Medium-Low	High	Low	Medium
Cowlitz	Medium-High	Medium	Low	Medium	Medium	Medium-High	Medium	Medium
Douglas	Low	Medium	High	Medium	Medium-Low	Medium	Low	Medium
Ferry	High	Medium	Low	Medium-Low	High	High	Medium	Medium-High
Franklin	Low	Medium	Medium	Medium	Low	Medium-Low	Medium-Low	Medium-Low
Garfield	Medium	High	Low	Low	Low	Medium-Low	High	Medium
Grant	Low	Medium-Low	High	Low	Medium-Low	Low	Medium-Low	Medium-Low
Grays Harbor	Medium	Medium-High	Medium	Medium	Medium	Medium	Medium	Medium
Island	Medium-Low	Medium-High	Low	Medium-High	Medium	Medium-High	High	Medium-High
Jefferson	High	High	Low	High	High	Medium	Medium-High	High
King	Medium	Medium	Medium	Medium	Medium	Medium	Medium-High	Medium

Landslide Risk Index (WaSRI L) and Constituent Landslide Exposure Ranks for Each County

County	Area	Population	Vulnerable Population	Built Environment	Critical Infrastructure	State Facilities	First Responder Facilities	Landslide Risk Index (WaSRI L)
Kitsap	Medium-Low	Medium-High	Low	Medium-High	High	Medium-High	High	Medium-High
Kittitas	Medium-High	Low	Low	Low	Medium-High	Low	Medium-Low	Medium-Low
Klickitat	Medium-Low	High	Low	High	Medium-High	High	Medium	Medium-High
Lewis	High	High	Medium-Low	High	High	Medium	Medium-High	High
Lincoln	Low	Low	Low	Low	Low	Medium-High	Medium-Low	Low
Mason	Medium	Medium-High	Medium-Low	Medium	Medium	Medium	Medium	Medium
Okanogan	Medium-High	Medium	Medium-High	Medium-Low	Medium-High	Medium-High	Medium	Medium-High
Pacific	Medium	Medium-High	Low	Medium-High	Medium-High	Medium	Low	Medium
Pend Oreille	Medium-High	Low	Low	Low	Medium	Low	Low	Low
Pierce	Medium	Medium-Low	Low	Medium-Low	Low	Medium-Low	Medium-Low	Low
San Juan	Low	Medium-Low	Low	Low	Low	Medium	Low	Low
Skagit	Medium-High	Medium-Low	Low	Low	Medium	Medium	Low	Medium-Low
Skamania	High	High	Low	High	High	High	High	High
Snohomish	Medium	Medium-Low	Low	Medium-Low	Medium-Low	Medium	Medium	Medium-Low
Spokane	Low	Medium-Low	Low	Low	Medium-Low	Low	Low	Low
Stevens	Medium-High	Medium-Low	Medium-Low	Medium-Low	Medium-High	Low	Medium	Medium
Thurston	Medium	Medium	Medium-Low	Medium	Medium	High	Medium-High	Medium-High
Wahkiakum	Medium-High	Medium-High	Low	High	Medium-Low	Medium-High	Medium	Medium-High
Walla Walla	Low	Low	Low	Low	Low	Medium-Low	Low	Low
Whatcom	Medium-High	Medium	Low	Medium-Low	Medium	Medium-High	Medium	Medium
Whitman	Low	Medium-Low	Low	Medium-Low	Medium	Medium-Low	Medium-Low	Low
Yakima	Medium	Medium-Low	Medium-High	Low	Medium	Low	Medium-Low	Medium-Low

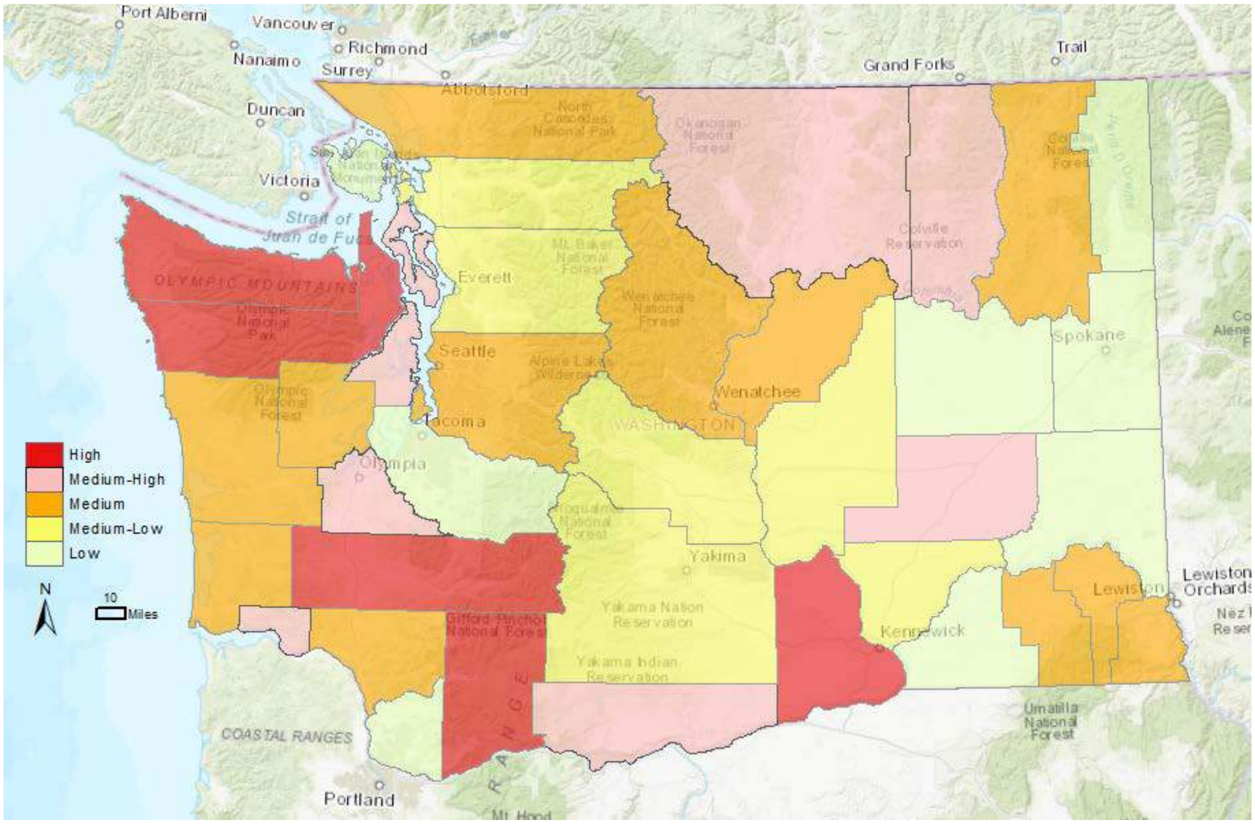


FIGURE L 9: LANDSLIDE RISK INDEX (WASRI – L)

Economic Consequences

It is expected that major landslides are unlikely to result in significant economic impact on the State GDP.

The economic activity data was derived from National Association of Counties. This dataset provides the county-level estimates of Gross Domestic Product (GDP) for 2016. The five counties ranked high on the landslide risk index contribute less than 5 percent of the state's Gross Domestic Product. Among the highest risk counties, Benton is the largest contributor to the state GDP. King County, the top contributor to the state GDP, is ranked medium for landslide risks. The other four counties – Pierce, Snohomish, Spokane, and Clark –among the top five contributors to State GDP are ranked low, except for Snohomish, which is ranked medium-low for landslide risks.

Landslide Risk (WaSRI L) and County GDP 2016		
County	**Landslide Risk Index (WaSRI L)**	**GDP 2016 (in Mil.)**
Adams	Medium-High	$746.07
Asotin	Medium	$618.43
Benton	High	$10,627.85
Chelan	Medium	$4,363.01
Clallam	High	$2,573.06

Landslide Risk (WaSRI L) and County GDP 2016		
County	Landslide Risk Index (WaSRI L)	GDP 2016 (in Mil.)
Clark	Low	$18,682.64
Columbia	Medium	$144.20
Cowlitz	Medium	$4,474.88
Douglas	Medium	$1,037.39
Ferry	Medium-High	$198.13
Franklin	Medium-Low	$3,356.16
Garfield	Medium	$97.44
Grant	Medium-Low	$3,803.65
Grays Harbor	Medium	$2,237.44
Island	Medium-High	$2,796.80
Jefferson	High	$867.23
King	Medium	$230,344.61
Kitsap	Medium-High	$12,082.18
Kittitas	Medium-Low	$1,566.21
Klickitat	Medium-High	$1,004.05
Lewis	High	$2,573.06
Lincoln	Low	$347.25
Mason	Medium	$1,566.21
Okanogan	Medium-High	$1,678.08
Pacific	Medium	$637.45
Pend Oreille	Low	$354.63
Pierce	Low	$41,280.80
San Juan	Low	$602.88
Skagit	Medium-Low	$5,705.48
Skamania	High	$218.04
Snohomish	Medium-Low	$39,378.97
Spokane	Low	$24,723.73
Stevens	Medium	$1,111.56
Thurston	Medium-High	$12,865.29
Wahkiakum	Medium-High	$93.41
Walla Walla	Low	$2,908.67
Whatcom	Medium	$10,068.49
Whitman	Low	$2,237.44
Yakima	Medium-Low	$10,404.10

Risk to Environment

To assess the risk to environmental resources, the spatial land cover mapped data was overlaid with landslide hazard layer. Forests, scrubland, wetland, and cropland areas were identified as ecologically critical areas. The overlap between these areas of ecological importance and landslide hazard was analyzed through spatial analysis in GIS software. It is estimated that 56 percent of the State's ecologically critical resources are in areas at risk from landslides. The high degree of overlap among the ecologically critical resources is expected because of the nature of the landslide hazard. Landslides are common in areas with steeper slopes and wet environments, which are also often locations of greater ecological diversity. The spatial analysis reveals that more than 50 percent of the ecologically sensitive areas in 25 counties are exposed to landslides. These counties include Chelan Clallam, Jefferson, Ferry, Lewis, Whatcom, Wahkiakum, Skamania, Cowlitz, Okanogan, Skagit, King, Kittitas, Pend Oreille, Asotin, Snohomish, Pacific, Stevens, Columbia, Pierce, Garfield, Yakima, Grays Harbor, Mason, and Island counties. In Chelan, Clallam, and Jefferson counties more than 90 percent of the ecologically critical areas exposed to landslides.

Landslides mobilizes soil, often stressing rehabilitative regeneration processes within upland denuded areas. This soil loss is often permanent. Also, landslide debris can block water courses resulting in flooding and extreme surges when blockages fail. These impacts often result in long-term changes that can be beneficial to fluvial habitats but detrimental to upland ones due to soil losses.

Environmentally Critical Areas at Risk from Landslides	
County	Percent of County Ecologically Critical Area with Landslide Exposure
Adams	6.80
Asotin	70.47
Benton	17.16
Chelan	95.74
Clallam	92.92
Clark	35.01
Columbia	64.45
Cowlitz	78.33
Douglas	19.57
Ferry	88.89
Franklin	5.79
Garfield	57.80
Grant	7.70
Grays Harbor	54.14
Island	50.47
Jefferson	90.70
King	72.70
Kitsap	39.73
Kittitas	72.66
Klickitat	37.48
Lewis	83.30
Lincoln	7.04
Mason	53.03
Okanogan	77.19
Pacific	69.69
Pend Oreille	71.19
Pierce	61.54
San Juan	23.63
Skagit	74.07
Skamania	79.32
Snohomish	69.85

Environmentally Critical Areas at Risk from Landslides	
County	Percent of County Ecologically Critical Area with Landslide Exposure
Spokane	16.83
Stevens	67.44
Thurston	47.66
Wahkiakum	80.45
Walla Walla	15.03
Whatcom	81.45
Whitman	9.98
Yakima	55.28
Washington State	55.93

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Public Health Communicable Disease Outbreaks, Epidemics, Pandemics

Risk Summary

Frequency – Communicable disease outbreaks occur annually in Washington. A global pandemic happens two or three times a century.

People –There is the potential for significant hospitalizations and loss of life from outbreaks of communicable diseases. According to the pandemic modeling software, FluAid, developed by the U.S. Centers for Disease Control and Prevention, more than 1 million people in Washington may become ill if a severe pandemic, such as the that occurred in 1918.

Property – Due to the nature of communicable disease, it is unlikely that any property impacts would be seen.

Economy – Except for a widespread influenza outbreak, an incident is unlikely to cause the loss of 1 percent of the state's Gross Domestic Product. Nonetheless, during an epidemic or pandemic, businesses may temporarily close thereby adversely affecting the state's economy. There could be implications for biosecurity at poultry or pig farms.

Environment – An incident is unlikely to cause significant environmental impacts.

State operations and facilities – An epidemic can cause widespread disruption of state operations as employees are unable to come to work.

First responders – First responders are among the most vulnerable to an outbreak, especially early on, as they come into contact with victims. Once the outbreak is identified, some of this risk can be mitigated by proper use of personal protection devices.

Public confidence – As seen during previous events, fear can quickly spread through social and traditional media. Officials must in turn provide personal protection recommendations and guidelines to reduce the risk to the public and provide regular updates on progress managing the outbreak.

Hazard assessment: Communicable disease outbreaks can be caused by many agents and transmitted in several ways. While public health measures have controlled many diseases in this country, there remains a risk from new agents such as new types of influenza or Severe Acute Respiratory Syndrome (SARS) that emerge with the potential to cause outbreaks.

Previous Occurrences: Washington has experienced communicable disease outbreaks, including influenza, pertussis, mumps, and foodborne illness. Annual flu season can stress the medical sector. On an international level, outbreaks include influenza, SARS, Zika, and cholera.

Probability of Future Events: Periodic outbreaks including influenza are a likely hazard in Washington. The state's connection to the global economy and the ease of national and international travel increases the risk of a new disease being introduced here. Additionally, natural disasters such as floods, earthquakes, or volcanic eruptions could result in displaced populations and mass sheltering which increase the potential for communicable disease outbreaks.

Jurisdictions at Greatest Risk: All jurisdictions are at risk for outbreaks due to reliance on national food processing and distribution networks and communicable diseases such as pertussis or influenza. The risk of outbreaks depends on factors such as population density, contact with animals, international travel and commerce, and access to health care.

Definitions:

Epidemic – As defined by the U.S. Centers for Disease Control and Prevention (CDC), an epidemic refers to an increase, often sudden, in the number of cases of a disease above what is normally expected for a given population over a given time period.

Outbreak – As defined by the CDC, an outbreak carries the same definition of an epidemic, but is often used for a more limited geographic area, jurisdiction, or group of people.

Pandemic – As defined by the CDC, a pandemic refers to an epidemic that has spread over several countries or continents, usually affecting a large number of people.

Special Note: This profile will not attempt to estimate potential losses to state facilities due to communicable disease outbreak. This hazard poses little threat to the built environment.

Epidemic Hazard Profile

Communicable disease outbreaks are defined by the U.S. Centers for Disease Control and Prevention (CDC) as the occurrence of more cases of disease than normally expected within a specific place or group of people over a given time period. Outbreaks may occur on a periodic basis (e.g., influenza), may occur rarely but result in severe disease (e.g., meningococcal meningitis), may occur after a disaster (e.g., cholera), or may represent an intentional release of an agent (e.g., bioterrorism). An epidemic is a disease occurring suddenly in humans in a community, region, or country in numbers in excess of normal (locally-defined), while a pandemic is the worldwide outbreak of a disease in humans in numbers clearly in excess of normal.

Agents causing outbreaks can be viruses, bacteria, parasites, fungi, or toxins. An individual may be exposed by breathing, eating or drinking, or having direct contact with an agent. These agents can be spread by people, contaminated food or water, healthcare procedure, animals, insects and other arthropods, or directly from the environment. Some agents, such as *Salmonella* or *E. coli* O157:H7, may have multiple means of spreading. Other agents, such as measles or pertussis, are spread only from one person to another.

History and Outlook

In the United States, better hygiene and water quality improved the health of the general population during the first half of the 20th century. The availability of medical care and vaccines further reduced communicable diseases. The availability of antibiotics after World War II enabled health care providers to treat many bacterial diseases. The development of vaccines assisted in the control of diseases such as chickenpox, mumps, polio, and measles. However, new strains of pathogens emerged, and anti-vaccination movements have created increased vulnerability to disease outbreaks. Additionally, growing disease agent resistance to antibiotics due to healthcare and agricultural practices continues to be a concern.

The spread of disease is determined by a multitude of factors, including personal choices such as lack of vaccination, poor hygiene, risky sexual practices, and shared needles by drug users. In addition, infected people who travel from country to country can be a source of transnational spread of disease, as occurred in the SARS outbreak in Asia and Canada in 2003. Other factors contributing to the spread of disease include economic growth and land use, global trade, and climate change. For example, development of land in areas previously unpopulated can bring humans into new environments for vector-borne diseases (for example, diseases carried by mosquitos, birds, or rodents). Imported foods such as cantaloupe, mangos, and seeds for alfalfa sprouts have been linked to *Salmonella* outbreaks while imported pets are a risk factor for emerging infections such as salmonellosis or monkey pox. Warmer-than-usual water and air can cause more bacterial growth in ocean waters which contaminate shellfish and can lead to an infectious outbreak.

While disease outbreaks are a routine occurrence across the world, epidemics and pandemics present serious risk to Washington. Several characteristics of pandemic or epidemic differentiate these episodes from other public health emergencies. First, an epidemic or pandemic has the potential to infect large numbers of residents and visitors and could easily overwhelm public health and medical systems in the state. A pandemic would also jeopardize essential community services by causing high levels of absenteeism in critical positions in every workforce. Basic public services such as health care, law enforcement, fire and emergency response, communications, transportation, and utilities could all be disrupted or severely reduced. Further, a pandemic or epidemic, unlike other public health emergencies, could last for several weeks or months. The stress on societal systems will increase since pandemics, by nature, affect many regions simultaneously and outside resources may be unavailable.

Emerging Threats

New agents are continually emerging to cause outbreaks in populations where immunity is low or nonexistent. In 1957 and 1968, new strains of influenza (flu) spread rapidly around the world. Although less severe than the 1918 flu strain which caused a global pandemic, these strains still resulted in many deaths. During the 1980s, human immunodeficiency virus (HIV) – the cause of acquired immune deficiency syndrome or AIDS – appeared. In the same years, tuberculosis (including strains harder to treat with antibiotics) increased in cities throughout United States. The 2009 pandemic of variant influenza H1N1 affected the entire globe with associated increased mortality.

An emerging agent may be entirely new, newly recognized, new to an area, or expanding its effect. A new or modified agent may emerge for one or more reasons:

- Changes in the agent, such as an increased resistance to antibiotics (e.g., MRSA or methicillin resistant *Staphylococcus aureus*)
- Altered climate or ecosystems due to economic growth, agriculture, deforestation, dams or irrigation. This could lead to a spread of mosquitoes due to irrigation or climate change, or exposure to Ebola during forest clearing, for example.
- International travel and commerce that spread diseases originating elsewhere (e.g., SARS, West Nile virus)
- Impacts of a globalized food supply or use of antibiotics on farms that could lead to salmonellosis from imported produce, for example.
- Breakdown of public health infrastructure. Lack of treatment or vaccinations could lead to an increase in some diseases, such as tuberculosis.
- Poverty and social inequalities that can reduce access to vaccines among some populations.
- Human behavior and demographics that lead to reduced level of vaccinated people, or outbreaks resulting from people in close quarters, for example, at a childcare center.
- Human susceptibility to infection caused by agents that suppress the immune system.

Disease Monitoring Systems

The Washington Administrative Code Chapter 246-101 (WAC) requires reporting of notifiable conditions by health care providers, laboratories, and health care facilities, as well as veterinarians, schools, child day care facilities, and food service establishments. Individual cases of certain conditions must be reported to the responsible local health jurisdiction for prompt public health actions to prevent outbreaks. The WAC also requires reporting of all outbreaks or suspected outbreaks of notifiable conditions, along with foodborne or waterborne diseases. Outbreaks or suspected outbreaks related to health care are also reported but not required by law (e.g., black fungus in steroid injections). The local health jurisdiction takes specific actions to identify the source of the agent and to control its spread utilizing public health interventions.

Disease Profiles

The following agents have the potential for causing ***significant*** disease outbreaks:

Influenza (flu) is a common respiratory infection that spreads among people and can cause serious illness and death. Annually, the flu puts significant strain on existing public health and medical systems. Antiviral treatment can reduce disease severity. Frequent small genetic changes in the influenza virus necessitate new vaccines because people lack immunity. These vaccines have varying degree of effectiveness as the mutated strains must be predicted. A large genetic change in influenza could result in a worldwide pandemic before an effective vaccine could be developed. CDC's FluAid pandemic modeling program forecasted that Washington State could have 5,000 fatalities, 10,000-24,000 patients needing hospitalization, and 480,000-1,119,000 outpatient visits from an influenza pandemic.

Severe Acute Respiratory Syndrome (SARS) and Middle East Respiratory Syndrome (MERS) are respiratory illnesses caused by corona viruses (SARS-CoV and MERS-CoV, respectively) that spread through droplet contact. In 2003, travelers carried SARS from Asia to more than two dozen countries in North America, South America, Europe, and Asia. A total of 8,098 cases occurred and 774 people died. Only eight people in the United States had laboratory evidence of SARS infection, all following travel to countries with SARS. Since 2012 there have been over 2,000 MERS cases and at least 750 deaths. Only two people in the United States had laboratory evidence of MERS infection, both following travel to countries with MERS. Washington state had no cases of either. There is no treatment and no vaccine for SARS or MERS.

Acquired Immune Deficiency Syndrome (AIDS) is an advanced stage disease caused by infection with Human Immunodeficiency Virus. AIDS is defined by certain opportunistic illnesses or other clinical outcomes and is often indicative of long-term HIV infection. HIV is mainly transmitted from person to person through sexual contact or exposure to blood. Antiviral treatments have greatly improved the survival of persons living with HIV infection. More than 12,000 people are currently living with HIV in Washington, about 55percent of which are in King County.

Tuberculosis (TB) most commonly presents as a respiratory illness caused primarily by the bacteria *Mycobacterium tuberculosis*. The bacteria are carried in airborne particles generated when persons who have pulmonary or laryngeal TB disease cough, sneeze, shout, or sing. In Washington, an average of four cases of TB disease are diagnosed each week. Since 2007, incidence rates of TB disease in Washington have progressed downward. While showing no change from the previous year, the rate of 2.9 cases per 100,000 in 2016 remains considerably lower than the period peak of 4.5 seen in 2007, and the 204 cases in 2016 represent a 1.4percent decrease from the 207 cases counted in 2015. Persons born outside of the United States account for more than three-quarters of TB cases in Washington. In 2016, Snohomish, King, and Pierce counties, with just over half of the state's population, reported a majority of all cases in Washington (77 percent).

Mosquito-borne diseases include West Nile virus (WNV), Zika, dengue, and malaria, among others. Competent vector mosquitos for WNV, western equine encephalitis, and St Louis encephalitis are present in Washington; however, only WNV has been reported in the past 30 years. West Nile virus can cause severe illness involving meningitis, paralysis, and coma, although this neuro-invasive presentation occurs in less than 1 percent of cases. The state does not have the type of mosquitos that carry dengue, Zika, or Yellow Fever, although travel-associated cases have been reported in the state and outbreaks have occurred in many parts of the Americas. Around 25-50 travel-related malaria cases are diagnosed in Washington each year.

E. coli are bacteria that normally live in the intestines of humans and animals, particularly cattle. Although most *E. coli* strains are harmless, strains producing Shiga toxin (STEC) can cause severe diarrhea and kidney damage. STEC can be spread by contaminated food (typically beef and produce), animal contact or water or among people if infected persons do not wash their hands after using the toilet or diapering children. Other bacterial agents that can cause severe diarrhea and occur in Washington include *Salmonella, Shigella,* and typhoid.

Intentional Release could occur for anthrax, botulinum toxin, smallpox, plague, or other potential agent of bioterrorism. Demands on the public health and medical systems would be extensive. Antibiotics could treat anthrax or plague, but there is only supportive treatment for botulinum toxin or smallpox.

The following agents have the potential for causing ***less serious*** disease outbreaks.

Multidrug-Resistant Organisms (MDRO) are bacteria that cannot be treated with the usual choices for antibiotics.

- Methicillin-Resistant *Staphylococcus Aureus* (MRSA) is an infection caused by *Staphylococcus aureus* bacteria — often called "staph." According to the CDC, in the general community MRSA most often causes skin infections. In some cases, it causes pneumonia (lung infection) and other issues. If left untreated, MRSA infections can become severe and cause sepsis – a life-threatening reaction to severe infection in the body.
- Carbapenem-Resistance Enterobacteriaceae (CRE) are several types of bacteria including *Klebsiella* species and *Escherichia coli (E. coli)* that are normally found in the human gut but can become carbapenum-resistant. The most common sources for infections with CRE are from patients themselves who are intestinally colonized or from a health care worker's hands while caring for patients.

Measles is a highly communicable viral rash illness that was a major childhood disease in the pre-vaccine era. Although the disease is now considered rare in Washington and the United States due to routine childhood immunization, sporadic cases of measles and outbreaks continue to occur. Risk of outbreaks increases in populations with lower vaccination rates.

Hepatitis – Hepatitis A, B, and C are viral infections that cause inflammation of the liver. Hepatitis A is usually transmitted by eating food prepared by or close contact with someone who is infected. It is usually a self-contained illness and infected persons that recover are immune. Hepatitis B is primarily transmitted through blood or sexual contact while Hepatitis C is primarily transmitted through blood exposures (sharing needles or other equipment to injection drugs). Hepatitis A and B can be prevented by vaccination. Acute Hepatitis A and B infections have decreased considerably during the past 15 years due to vaccination and reductions in sexual or blood borne transmission. Reported number of acute Hepatitis C cases has increased in recent years, possibly related to injection drug use. In 2017, large outbreaks of Hepatitis A have occurred among populations experiencing homelessness in several states including California and Michigan. Chronic Hepatitis B and C remain challenges to the public health and medical systems.

Lyme Disease is caused by *Borrelia burgdorferii* and is transmitted to humans by tick bites. Typical symptoms include a "bull's eye" rash along with fever, headache, and muscle pain. The Washington Department of Health in recent years has received up to 6 reports annually of locally acquired Lyme disease; the majority of reported cases are travel-associated. Although little is known about the epidemiology of Lyme disease in Washington, the risk of infection appears to be highest in counties around and west of the Cascade Mountains, reflecting the distribution of the local *Ixodes pacificus* tick vector.

Hantavirus Pulmonary Syndrome (HPS), caused by Sin Nombre virus, causes a rapidly progressive and severe pneumonia that can be fatal. The disease is transmitted via inhalation of droppings from infected deer mice. Between 1 and 5 cases occur annually in the state, of which, 33 percent are fatal.

Leptospirosis is a disease caused by *Leptospira* bacteria that can occur in both humans and domestic animals. Symptoms can include fever, meningitis, and impaired liver and kidney function, among others. Leptospirosis is rare in Washington, with up to five cases reported each year.

Previous Occurrences

Influenza

Pandemics of influenza have occurred throughout recorded history and documented since the 16th century. Beginning with a pandemic of influenza-like disease occurring in 1520 there have been 31 documented cases of probable influenza pandemics. Intervals between previous pandemics have varied from 11 to 42 years with no recognizable pattern. Three pandemics occurred in the last century, in 1968/69, 1957/58 and 1918/19 and a pandemic occurring in this century in 2009.

It is estimated that approximately 20 to 40 percent of the worldwide population became ill during the 1918/19 influenza pandemic. Consensus among experts is that the death toll was at least 40 million with some estimating it could have been as high as 50 to 100 million deaths. Between September 1918 and April 1919, approximately 500,000 to 650,000 deaths from the pandemic flu occurred in the United States. Western Samoa and Iceland were the only countries to avoid the 1918 flu entirely due to the use of strict travel restrictions during the pandemic.

The 1957/58 influenza pandemic was much milder than that of the 1918 pandemic, with the global death toll reaching 2 million. The 1968 Hong Kong Flu outbreak is thought to have caused around 1 million deaths worldwide, resulting in nearly 34,000 deaths in the United States. Due to advances in science from the 1918/19 influenza, worldwide vaccine production began during the pandemics of 1957/58 and 1968/69, likely lessening the death rates for both events.

The 2009/2010 novel influenza A (H1N1) was a new flu virus of swine origin that first caused illness in Mexico and the United States in March and April 2009. By June 2009, all 50 states in the United States, the District of Columbia and Puerto Rico reported cases of novel H1N1 infection. The nationwide U.S. influenza surveillance systems reported children and pregnant women particularly affected. The Washington Department of Health reported 1,516 hospitalizations and 99 fatalities from laboratory confirmed influenza H1N1 cases.

New influenza strains can come from swine or poultry. If an outbreak occurred of a pig or bird influenza strain, preventive measures would be needed to prevent infected people from working on farms with large populations of swine or poultry.

Foodborne and Animal Related Enteric Outbreaks

Foodborne and animal-related gastro-intestinal outbreaks occur every year in Washington due to bacteria, viruses, parasites, and toxins. Common causes are norovirus, *Campylobacter*, *Salmonella*, *Shigella*, and Shiga toxin-producing *E.* coli (STEC). Although restaurant and commercial exposures are most commonly reported as the cause of outbreaks, it is likely that many more small clusters of illness occur due to mishandled food in the home setting.

Annually, 30-50 foodborne disease outbreaks are reported in Washington State with 300-700 illnesses associated with these outbreaks. Recently there have been Salmonella illnesses linked to eating pork, raw beef, and commercially prepared chicken salad. Recent STEC outbreaks have been associated with ground beef, sprouts and menu items from a fast-food Mexican restaurant chain.

Table 11 Washington Foodborne Disease

Year	Cases	Outbreaks
1997	810	108
1998	706	60
1999	1164	93
2000	938	66
2001	574	69
2002	704	56
2003	620	55
2004	679	58
2005	390	42
2006	677	51
2007	722	43
2008	564	46
2009	307	27
2010	344	37
2011	371	30
2012	552	27
2013	437	37
2014	432	45
2015	505	36
2016	543	49

Source: Washington State Communicable Disease Report 2016

Pertussis

Pertussis (whooping cough) affected most Washington counties during a statewide outbreak in 2012, with more than 4,900 cases reported, the highest number since 1941. The number of cases reported each year varies considerably, ranging from 96 to 1,026 cases a year in the 20 years prior to the statewide outbreak in 2012 (1992-2011), a time during which nine babies with pertussis died. There is also a variation in the rate of reported disease among health jurisdictions, reflecting local outbreaks.

West Nile Virus

West Nile Virus was first identified in the US in 1999; the first cases in Washington were reported in 2006. It can affect people, horses, migratory birds (especially waterfowl), and other animals. Generally, up to 10 cases are reported to DOH each year, with peaks of 38 and 22 locally acquired cases in 2009 and 2015, respectively. Increasing numbers of dead birds in a focused area may be an indication of West Nile virus transmission.

Probability of Future Events

There are expected periodic outbreaks of certain communicable diseases. Each winter there is an influenza season, with 10-20 percent of the state population affected. Washington has 30 to 50 foodborne outbreaks reported each year. Other outbreaks such as pertussis or Hepatitis A may occur every few years while measles outbreaks are rare.

Through Washington's numerous connections to the national and global economies, including a shared international border, there is elevated potential for disease introduction due to several factors: the large number of travelers arriving daily at land, air or sea ports and the intentional or inadvertent importation of infected animals.

Following a disaster such as an earthquake, volcanic eruption, or tsunami, communicable disease outbreaks could result from lack of safe water and food, disruption of waste treatment, and mass sheltering of people. However, the existing public health structure has minimized the presence of potential agents such as measles, typhoid, or hepatitis in the population so large outbreaks are less likely in this country than elsewhere on the globe. Mass sheltering is more likely to result in outbreaks of mild to moderate respiratory infections, viral gastroenteritis, and skin infections.

Determining the probability of future public health events is difficult. There are many factors which influence the probability of future outbreaks of disease. These include:

- Increased proximity between animals and people.
- Transportation of infected patients from one health care facility to another.
- Infected or ill travelers coming into the region by land, sea or air ports.
- Importation of intentionally or unrecognized infected animals such as pets, or animal products used as a food source, such as imported beef, fowl or seafood.
- Illegal sale of banned or dangerous animals.
- Migratory birds.

According to the Washington State Department of Health publication, "Preparing for Pandemic," a pandemic influenza outbreak could kill hundreds of thousands of Americans and possibly 40,000 Washington citizens. Unlike the ordinary flu, people of any age and health condition can become seriously ill and no one will have immunity to a pandemic flu virus. The elderly and young children, normally considered most vulnerable populations in a pandemic, may be joined by other populations not normally considered vulnerable. For example, deaths of 20- to 40-year-olds, a population not thought to be vulnerable, were disproportionate to their size of their population during the 1918 pandemic Pregnant women were disproportionately affected in the 2009 flu outbreak.

Jurisdictions Most Vulnerable to Communicable Disease Outbreaks

More densely populated areas have a greater risk for the spread of agents among humans, while areas with a higher density of animals may have a higher potential for acquiring diseases from animals. Urban areas are more likely to require mass sheltering following a disaster, which has an inherent potential for augmented disease transmission. Conversely, rural areas may have more limited options for health care access, which can hamper disease mitigation efforts. The Puget Sound region has international air and seaports which serve large populations of humans and animals from across the planet. Immigrant and marginalized populations are more vulnerable to communicable disease outbreaks due to likelihood of travel to at-risk regions and limited access to healthcare. Therefore, the whole state remains vulnerable to the various communicable diseases discussed.

Economic Impacts

The impacts of any large disease outbreak can be severe, and could result in increased deaths, economic hardship from lost work time, and loss of productivity. In particular, pandemic influenza or other severe respiratory disease causing many cases with a high death rate could result in severe social disruption and major economic impacts. Other communicable disease outbreaks are likely to have only local impact on businesses, industries, transportation systems, or governmental agencies.

Potential Climate Change Impacts

Rising carbon dioxide and other greenhouse gases are warming the climate system, disrupting historic climate patterns around the globe and here in the Pacific Northwest. Washington has already seen increased temperatures, overall declines in glaciers and snowpack, earlier peak stream flow in snowmelt fed rivers, and sea level rise along some coastlines. In the coming decades, climate scientists predict further decline in Washington's snowpack, more frequent water shortages in some basins, sea level rise, sea surface warming, ocean acidification and other marine water impacts, increasing flood risk, more acres burned from wildfires, and shifts in the range of plants and wildlife living in Washington.[1]

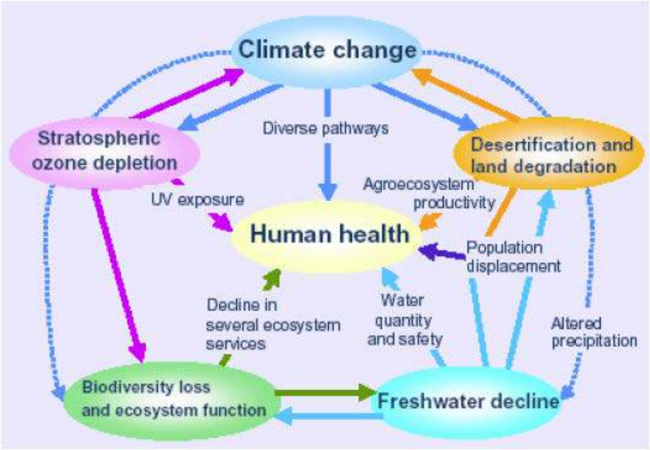

FIGURE PH1 HUMAN HEALTH AND THE EFFECTS OF CLIMATE CHANGE

These and other changes influence the potential for outbreaks of disease from environmental pathogens and other infectious conditions that are directly or indirectly influenced by weather and climate. For example, expansion of geographic distribution and earlier seasonal activity of ticks, mosquitos, rodents and other animals could increase Washington residents' in-state or travel associated exposures to vector borne diseases like Lyme disease, West Nile virus, Dengue, Zika and Hantavirus.[1, 2]

Rising temperatures, changes in humidity and more extreme weather events are also expected to increase exposure of food to some pathogens, including bacteria like *E. Coli* and salmonella, although prevention strategies can substantially reduce the risk of foodborne illnesses. Increases in sea surface temperature and other changes in marine conditions are expected to favor growth of bacteria such as Vibrio, impacting shellfish food safety.[2]

Risk of waterborne illness outbreaks may also increase. Heavy precipitation events and associated runoff, along with expected increases in flooding, will compromise the quality of recreational waters and drinking water sources. Increased frequency or severity of these events could strain or break the infrastructure providing treatment barriers that typically prevent human exposures to waterborne pathogens.[2]

While everyone's health will be affected by climate change, the health impacts will not be experienced equally. In the U.S. and within the Pacific Northwest, different regions will experience climate impacts in different ways, and associated health risks will vary by age, life stage and other social determinants of health.[2]

Climate change is also expected to increase health disparities by disproportionately impacting those who already bear a larger burden of risk factors and illness, such as people with lower income, indigenous communities, people with existing chronic disease, the socially isolated, those with a disability, immigrant and refugee populations who may have less English language fluency, and some communities of color.[2]

Many health impacts associated with climate change can be avoided if concerted action is taken to strengthen key features of public health and health care systems, such as maintaining robust risk monitoring and disease surveillance, implementing early warning systems, and continuously improving the cultural and linguistic appropriateness of health protection messages to reduce vulnerability to climate-sensitive risks.

1. Snover, A.K.M., G.S.; Whitely Binder, L.C.; Krosby M; Tohver I, *Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers*. 2013, Univesity of Washington, Climate Impacts Group: Seattle, WA. Website: https://cig.uw.edu/resources/special-reports/wa-sok/

2. *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment.*, A. Crimmins, J. Balbus, J.L. Gamble, C.B. Beard, J.E. Bell, D. Dodgen, R.J. Eisen, N. Fann, M.D. Hawkins, S.C. Herring, L. Jantarasami, D.M. Mills, S. Saha, M.C. Sarofim, J. Trtanj, and L. Ziska, Editor. 2016, U.S. Global Change Research Program: Washington, DC. p. 312. Website: https://health2016.globalchange.gov/downloads

Mitigation Activities

A safe water supply, good hygiene, effective sewage and waste disposal, aggressive monitoring, public education, prevention, and prophylaxis and treatment are the primary mitigation efforts for potential pandemic/epidemic outbreaks. Individual actions such as frequent hand washings, covering one's mouth when they cough, and staying home when ill have an enormous impact on maintaining control of an infectious disease by limiting the spread of germs.

Basic mitigation measures also include: childhood and adult immunization programs; health education in the schools and on a community level to address disease transmission and prevention; targeting the mechanism of transmission, such as drug usage for diseases like HIV infection and Hepatitis B and C; maintaining strict safe food handling by food service employees and food establishments; maintaining strict standards for production of food products; and utilizing accepted and recommended infection control practices in medical facilities.

Large-scale outbreaks might require additional interventions such as:

- Education of the public, health care providers, and public health system
- Enhanced disease surveillance
- Greater emphasis on general hygiene measures (food, water, sewage, respiratory hygiene)
- Isolation of cases
- Quarantine of contacts
- Mass distribution of medication for prophylaxis or treatment
- Mass immunization of the public
- Alternate care facilities (acute disease, chronic care)
- Increased medical examinations
- Seizure of unsanitary medical equipment
- Provisioning food, water, and shelter
- Closing schools, businesses, entertainment venues, recreational events
- Establishing travel restrictions
- Conducting mass evacuation
- Mass burials of human and animal remains
- Disposal of contaminated material
- Decontamination of environment

Official Mitigation and Response Capacities

Special public health response planning would be necessary for large-scale community measures such as distribution of medical materiel, mass prophylaxis, and mass vaccinations. This could involve national resources like the CDC's Strategic National Stockpile.

U.S. Department of Health and Human Services (HHS) staff operates the nation’s strategic national stockpile of medical resources, equipment, and services for augmenting state response to dangerous diseases, chemicals, or other hazards. The SNS is organized for flexible response and delivery of medical materiel quickly by using several different concepts: 12-Hour Push Packages, managed inventory, and rapid purchasing power. Washington has a formal state plan within the Comprehensive Emergency Management Plan (CEMP), ESF 8 – Health Systems, Appendix 1, to request and take delivery of SNS resources and distribute them onto local jurisdictions.

Rapid Purchasing Power: CDC can provide additional medications and medical supplies through contracts with the Veterans Administration. CDC can use this mechanism during an emergency to rapidly procure additional materials that are not typically part of the stockpile.

At Risk State Facilities

This profile will not attempt to estimate potential losses to state facilities due to communicable disease outbreak. This hazard poses little threat to the built environment, but can pose significant risk and damage to the state's economy and citizens, residents and tourists.

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Radiological Incident Hazard Profile

Risk Summary

The Washington Fixed Nuclear Facility Protection Plan maintained by the Washington State Emergency Management Division provides guidance to state agencies in the event of a radiological material incident. For radiological incidents, this plan covers incidents that may occur at the U.S. Department of Energy's Hanford Site, Energy Northwest's Columbia Generating Station nuclear power plant, for the U.S. Navy bases located in the Puget Sound region, and for operations at Framatome Richland Engineering and Manufacturing Facility (EMF). Of these four risk sources, the Hanford Site and Columbia Generating Station present the greatest risk to Washington.

Frequency – There has not been a significant release of radiological material in Washington in the past 50 years.

People - Though radiological releases can adversely affect people, the likelihood that a release would cause significant injury to or kill more than 1,000 people is highly unlikely. As of 2016, the total population in the Columbia Generating Station 10-mile Emergency Planning Zone (EPZ) is 72,463[i].

Property – A radiological release from the Columbia Generating Station would result in the permanent relocation of population in the impacted areas of the communities. Therefore, the property and buildings loss could amount to millions of dollars.

Economy – The state's $51 billion food and agriculture industry employs approximately 164,000 people and contributes 12% percent to the state's economy. While the direct economic impact from a radiological release would be isolated to the areas exposed to the radioactive isotopes, the greater impact is the cascading effects to the agricultural community. A release would result in the establishment of a Food Control Area and potential embargoes. Public fear would likely lead to consumers no longer buying agricultural products from the State of Washington. Total economic impacts could result in billions of dollars per year in loss.

Environment – The environment and species that inhabit the areas in and around a radiological release can be adversely affected in an event. Saddle Mountain National Wildlife Refuge is located within the 50-mile Ingestion Planning Zone. This refuge is home to rare and endangered species such as the Columbia River steelhead, Chinook salmon, Columbia Basin pygmy rabbit, persistent-sepal yellowcress, Umtanum desert buckwheat, and the White Bluffs bladderpod.[ii]

State Operations and Facilities – Impacts to state operations and facilities is limited to within the areas exposed to radiological release. State agencies with operations and facilities within exposed areas may need to activate their Continuity of Operations Plan (COOP).

First Responders –A response to a radiological emergency may place emergency response personnel in a unique situation where they must adhere to and be mindful of radiological exposure and contamination as they conduct response activities. This response requires additional protective measures for emergency workers to ensure exposure is limited to within the acceptable dose rates.

Public Confidence – A radiological release is likely to lead to widespread public fear and impact public confidence in government ability to protect life safety and the safety of fresh and processed products from within the impacted areas.

Jurisdictions at greatest risk – There are eight counties within the 50-mile Ingestion Planning Zone for the Columbia Generating Station or the Hanford Reservation. The eight counties are Benton, Franklin, Walla Walla, Grant, Yakima, Adams, Klickitat, and Kittititas.

Radioactive Materials

The Washington State Department of Health licenses nearly 400 facilities in the state that use radioactive materials. These are categorized in three major groups: medical, industrial, and laboratory. Hospitals, clinics, laboratories, and research facilities routinely use radiation in the diagnosis and treatment of medical and dental patients. Industrial applications include various flow gauges, research and development facilities, and radiography to non-destructive test welds and castings for flaws. Additionally, military bases that receive, ship, and store nuclear materials include Puget Sound Naval Shipyard at Bremerton, Naval Submarine Base Bangor, Joint Lewis-McChord Base, and Fairchild Air Force Base. A specific Department of Health license is required to receive, possess, use, transfer, or acquire most radioactive materials. Licensees and registrants are periodically inspected for regulation compliance, material use and handling, personnel training, security, transportation, and other important factors that correspond with the possession of radiological materials.

There are five major types of ionizing radiation with various penetration abilities.

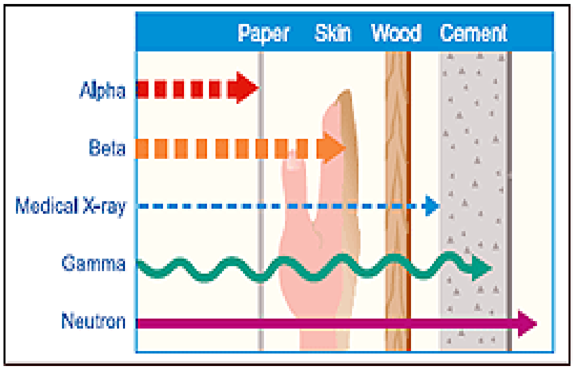
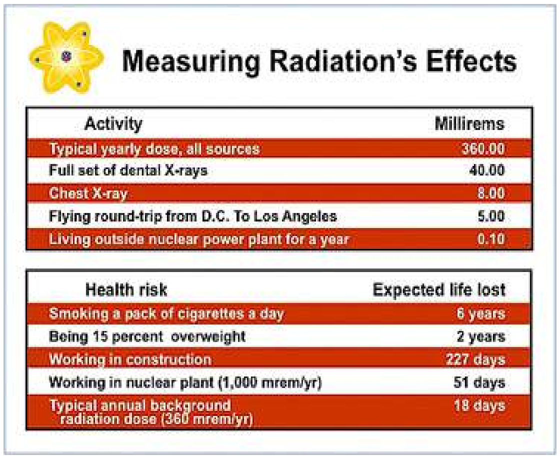


FIGURE 25 IONIZING RADIATION ABILITIES



Measuring Radiation's Effects

Activity	Millirems
Typical yearly dose, all sources	360.00
Full set of dental X-rays	40.00
Chest X-ray	8.00
Flying round-trip from D.C. To Los Angeles	5.00
Living outside nuclear power plant for a year	0.10

Health risk	Expected life lost
Smoking a pack of cigarettes a day	6 years
Being 15 percent overweight	2 years
Working in construction	227 days
Working in nuclear plant (1,000 mrem/yr)	51 days
Typical annual background radiation dose (360 mrem/yr)	18 days

FIGURE 26 RADIATION EXPOSURE LEVELS AND EFFECTS

Hanford Site[iii, iv, v]

The Hanford Site was built by the US government in 1943 for the Manhattan Project, the wartime effort to build the atomic bomb. The 560-square mile site bordering 51 miles of the Columbia River near the cities of Richland, Pasco, and Kennewick, Washington, is the most contaminated site in North America, holding more than 60 percent of the nation's highly radioactive and chemically hazardous wastes. These 53 million gallons of high level radioactive hazardous wastes are stored in 177 underground tanks, 149 of which are leak-prone, single-shelled tanks posing a serious threat to the land, the nearby Columbia River, human health and the region's economy. Already, 67 of the single-shelled tanks have leaked about one million gallons of highly toxic contaminants into the ground and are moving through groundwater toward the Columbia River. In 2008, it was estimated that if cleanup does not proceed on schedule, the contamination will reach the Columbia River in 12 to 50 years depending on the specific location and type of contamination.

Approximately one million people live in the 42 cities and towns downstream from the Hanford site. About 8,000 farms worth an estimated $6.4 billion are located in and around these communities. The region contributes to 10 percent of Washington's overall economy and 30 percent of Oregon's economy.

The most recent significant release of radioactive hazardous waste at the Hanford Site tank farm was on July 27, 2007. Contractor CH2M Hill Hanford Group was pumping waste from a single-shell tank and tried to unblock the pump by running it in reverse when "Over 80 gallons of highly radioactive tank waste spilled," according to the manager of Ecology's Nuclear Waste Program. Upon investigating the circumstances around the spill, Ecology determined a series of administrative and engineering failures contributed to the accident including inadequacies in the design of the waste retrieval system.

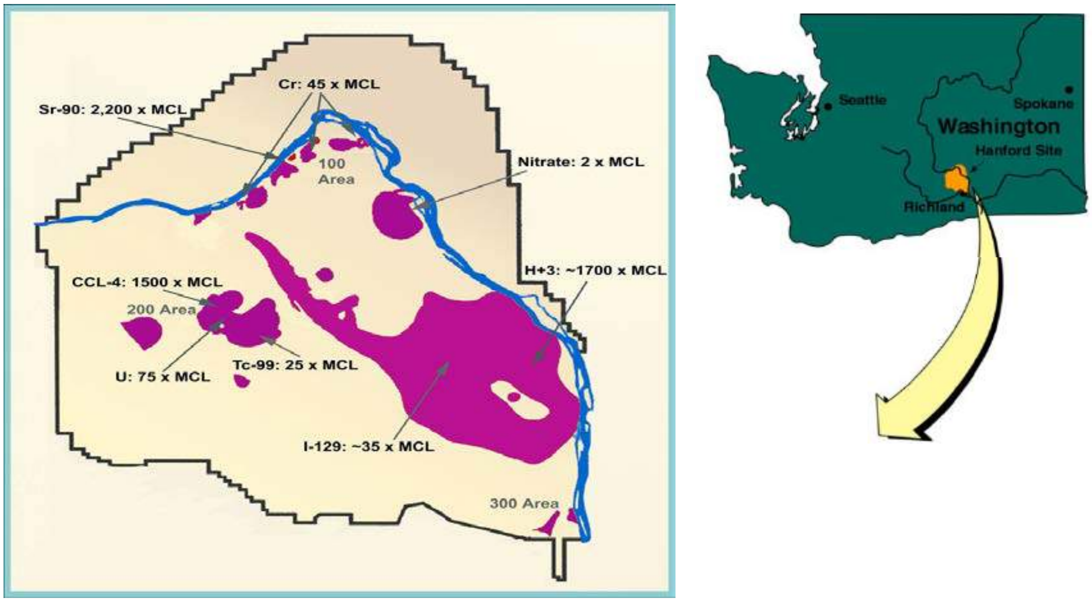


FIGURE 27 COMBINED CHEMICAL AND RADIOLOGICAL GROUNDWATER CONTAMINATION (PURPLE AREAS) ABOVE DRINKING WATER STANDARD: APPROXIMATELY 80 SQUARE MILES

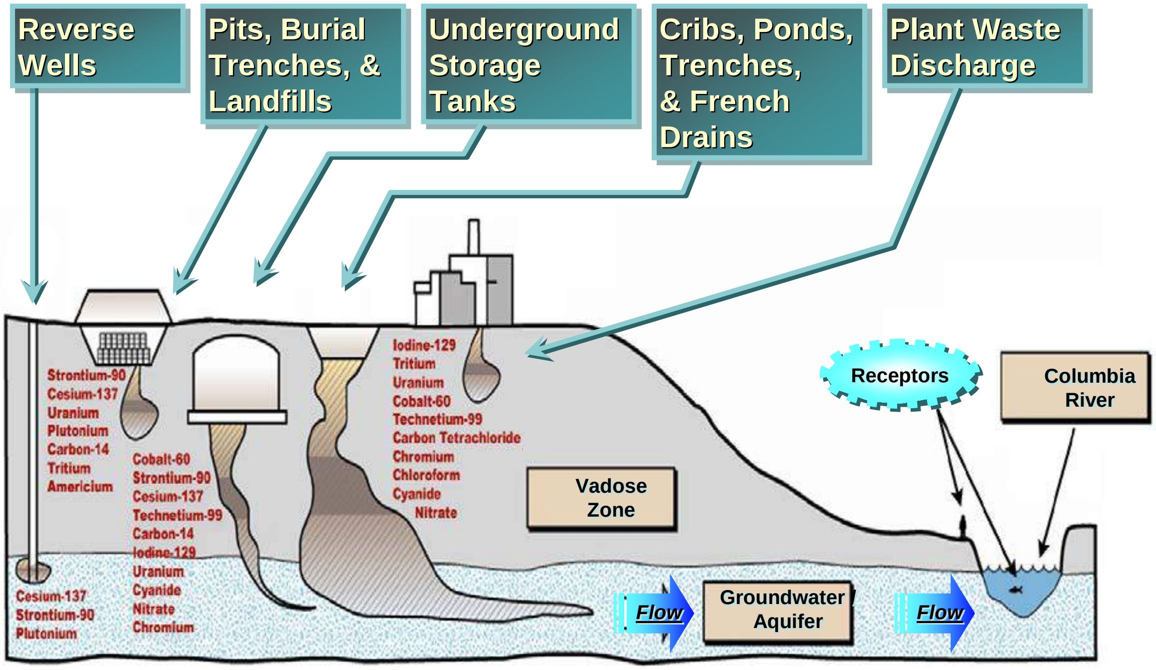


FIGURE 28 HANFORD SOURCES OF CONTAMINATION

In 2017, the Department of Energy revised the Emergency Planning Zones (EPZs) for the areas on the Hanford Site. The EPZs reduced in size from the previous risk assessment. This is due to the reduced risk at these areas as a result of ongoing efforts to clean up the site. The map below contains the updated EPZs.

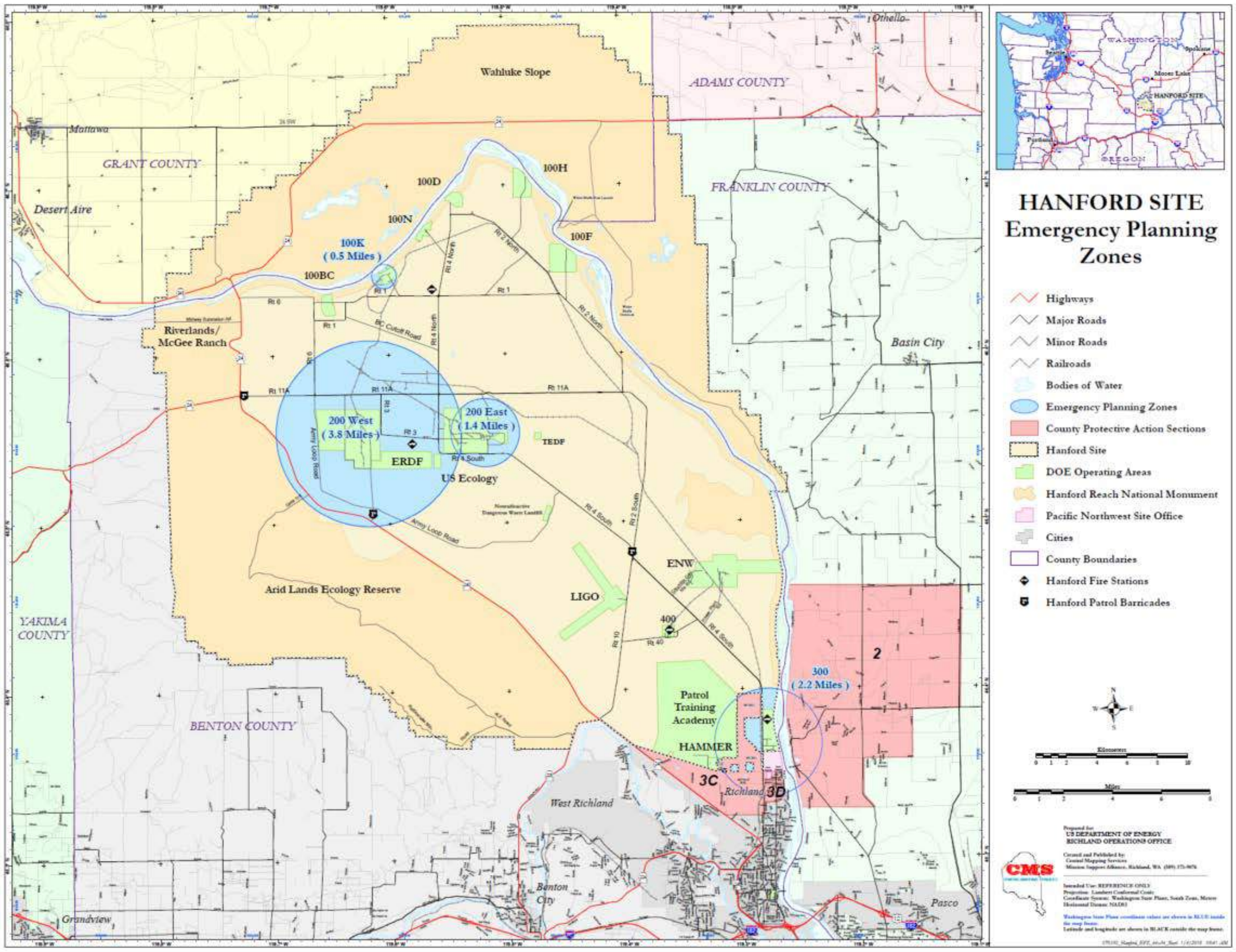


FIGURE 29 HANFORD SITE EMERGENCY PLANNING ZONES, JANUARY 2018

Columbia Generating Station [vi]

The Columbia Generating Station (CGS) is located on the Hanford Site about 10 miles north of Richland and 2 miles west of the Columbia River. Energy Northwest's CGS is Washington’s only operating commercial nuclear power plant. CGS is a boiling water reactor and produces 1,150 megawatts of electricity and began delivering power in 1984. This electricity is sold at cost to Bonneville Power Administration (BPA).

CGS is a reliable energy producer. Unlike hydro, wind, and solar generation facilities, CGS is not dependent on weather conditions — it will produce electricity 24 hours a day, 7 days a week. In addition, operators are able to adjust power levels to meet Bonneville Power Administration’s needs based on river and wind conditions referred to as “load following.” Refueling and maintenance outages occur every two years during the spring, when the Columbia River Basin has ample runoff to generate electricity through hydroelectric turbines.

Since the retirement of Oregon's Trojan Nuclear Plant, CGS is the only fully licensed commercial reactor in the northwestern United States. In 2000, Washington Public Power System changed its name to Energy Northwest and the plant's name to the Columbia Generating Station. CGS has a license to operate through December 20, 2043.

There have been several worldwide nuclear release accidents but there have been no incidents of radiological release at the Columbia Generating Station. A list of some of the minor incidents that have occurred at CGS is below.

Date	Table 8 Incident Description	Notification Level
14 May 1997	**Explosion at the Plutonium Reclamation Facility (200 West Area)**	**Alert**
28 January 1998	**Picric Acid crystals found in 327 building (300 Area)**	**Alert**
28 June 2000	**24 COMMAND Range Fire (started in Benton County and came on-site. Threatened multiple facilities throughout the Hanford Site)**	**Alert**
24 August 2005	**Solid Waste Storage and Disposal Facility incident(200 West Area)**	**Alert**
25 June 2004	**Radiography vehicle stolen, vehicle later recovered**	**Alert**
30 July 2004	**Failure of two control rods to properly insert into the reactor**	**Alert**
6 November 2005	**Fast Flux Test Facility (FFTF) incident (400 Area)**	**Alert**
28 March 2006	**Range brush fire threatened the protected area near CGS**	**Alert**

Table 1 Minor incidents that have occurred at CGS in recent history

The primary concern at the Columbia Generating Station is a potential release of radiological material. To ensure the likelihood that impact to people and agricultural products is minimized, emergency plans are in place and exercises conducted in accordance with Federal regulations. In addition, safety inspections are performed at the plant to ensure proper operation and safety procedures are followed.

Benton County Emergency Services, Franklin County Emergency Management, the State of Washington, and Energy Northwest developed plans to respond in the event of an incident at CGS. These plans are designed to help protect area residents living nearby and to protect people from ingesting fresh food products that may have been contaminated by radiological materials.[vii] These plans are reviewed, exercised, and updated routinely.

Two Emergency Planning Zones have been established to protect the public in the event of an incident at Columbia. A 10-mile emergency planning zone (EPZ) is designed to protect residents from direct exposure to radiation in the event of a release of radioactive material. In 2017, Columbia Generating Station completed a Population Update Analysis. The population numbers for the plume EPZ are listed in the table below.

The 50-mile emergency planning zone is designed to keep people from consuming potentially contaminated fresh food and milk products by keeping those products out of the marketplace.

Examples of fresh food products that can become contaminated with radiation are milk, fresh fruits, vegetables, processed products and grains as well as open water sources.[viii]

Table 2: Population Change as per Washington State OFM[ix]

County	2010 Population	2016 Population	Percent Change
Benton	175,177	190,500	8.75%
Franklin	78,163	88,670	13.44%
Municipality	**2010 Population**	**2016 Population**	**Percent Change**
Benton County, WA			
EPZ			
Richland	48,058	54,989	14.30%
West Richland	11,811	14,198	19.99%
Shadow Region			
Benton City	3,038	3,276	8.05%
Franklin County, WA			
Shadow Region			
Pasco	59,781	70,579	15.54%

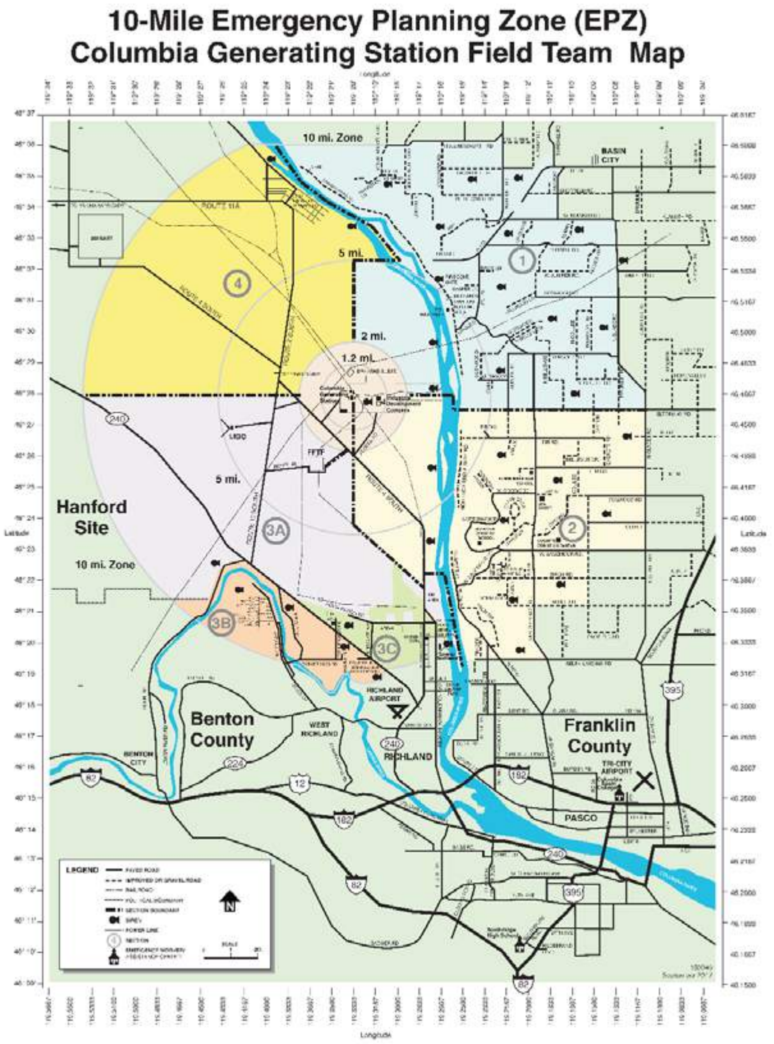


FIGURE 30 COLUMBIA GENERATING STATION 10-MILE EPZ, SEPTEMBER 2017

Naval Nuclear Propulsion Program

Because of differences in the design and operation of naval nuclear propulsion plants when compared to commercial nuclear power plants, the exposure to the public would be localized and not severe in the highly unlikely event of a release of radioactivity from a ship.

To assist state and local authorities in assessing the need for any preplanning in the vicinity of naval bases or shipyard where nuclear powered vessels are berthed, the Naval Nuclear Propulsion Program has designated Areas of Planning Attention (APA). The APA extends 0.5-miles around every location where nuclear-powered vessels are normally berthed (i.e. from the actual dock or pier, not the shipyard or naval base property boundary). The 0.5-mile distance is based on detailed, conservative analysis of worst-case, highly unlikely scenarios. The actual radius of the impacted downwind area will most likely be smaller.

For Naval Base Kitsap-Bremerton and Naval Station Everett, only small portions (e.g. a few city blocks) of the APA cross over the Federal Government property boundaries. For Naval Base Kitsap-Bangor, the APA is completely within Federal Government property boundaries except for areas in the Hood Canal

Framatome (Formerly Areva NP)

The operations at Framatome Richland Engineering and Manufacturing Facility (EMF) are related to the development and fabrication of UO2 fuels for commercial nuclear reactors. This includes receipt, possession, storage, transfer, and all operational steps from UF6 UO2 conversion to packaging finished fuel elements, associated uranium scrap recycling, and waste treatment and disposal.

Fuel cycle and materials facilities (like the Framatome Richland EMF) do not present nearly the degree of radiological hazard (by orders of magnitude less) that nuclear power plants do. The NRC classification system at the fuel facility requires the use of only two emergency classification levels, Alert and Site Area Emergency. Alert represents the least severe condition and Site Area Emergency the most severe.

An Alert is defined as an incident that has led or could lead to a release to the environment of radioactive material or other hazardous material, but the release is not expected to require a response by an offsite response organization to protect persons offsite. An Alert reflects mobilization of the facility’s emergency response organization, either in a standby mode that will activate some portions of the facility’s emergency response organization or full mobilization but does not indicate an expectation of offsite consequences. However, an Alert may require offsite response organizations to respond to an onsite condition.

A Site Area Emergency is defined as an incident that has led or could lead to a significant release to the environment of radioactive or other hazardous material and that could require a response by an offsite organization to protect persons offsite. A Site Area Emergency reflects full mobilization of the facility’s emergency response organization and may result in requests for offsite organizations to respond to the site.

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[i] “Columbia Generating Station Population Update Analysis,” KLD Engineering, P.C., 2017

[ii] Hanford Reach National Monument, https://www.fws.gov/refuge/Hanford_Reach/Wildlife_Habitat/ . retrieved August 3, 2018.

[iii] Information from Department of Ecology Hanford website, http://www.ecy.wa.gov/features/hanford/index.htm, retrieved April 4, 2008.

[iv] “Hanford Overview,” slideshow presentation prepared by Jane Hedges, Nuclear Waste Program Ecology, Dave Workman, communication and Education Ecology, and Andrew fitz, Office of the Attorney General, August 31, 2006, retrieved from http://www.ecy.wa.gov/features/hanford/OFM_hanford_083106.ppt on April 8, 2008.

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[v] "Ecology Issues $500,000 fine for Hanford Tank Waste Spill," Department of Ecology News Release, December 4, 2007, retrieved from http://www.ecy.wa.gov/news/2007news/2007-356.html on April 8, 2008.

[vi] "Hanford Site Virtual Tours – Energy Northwest," *DOE Hanford Site*, December 12, 2006, <http://hanford.gov/?page=338&parent=326> (January 24, 2008).

[vii] "Columbia Generating Station," *Benton County Emergency Services*, n.d., <http:www.bces.wa.gov/columbia_generating_station.htm> (October 28, 2008).

[viii] "Emergency Preparedness for Nuclear Facilities in Washington State," *WA State Dept. of Agriculture*, December 2007, <http://www.agr.wa.gov/FoodSecurity/Attachments/Trifold07.pdf> (November 13, 2008).

[ix] "Columbia Generating Station Population Update Analysis," KLD Engineering, P.C., 2017

Severe Weather Risk Summary

Washington State Risk Index for Severe Weather (WaSRI-SW)	**HIGH**
LIKELIHOOD	🟨

There is a high likelihood of numerous severe weather events annually. Many of these will be small weather anomalies that may not develop into a large event. Our changing climate will continue to increase their frequency and intensity.

HAZARD AREA	HIGH

Nearly all of the state is exposed to some kind of severe weather event.

POPULATION	

About 47% of the state population resides in areas exposed to medium or higher severe weather events.

VULNERABLE POPULATION	

Less than 10% of the state population resides in areas ranked medium or higher on social vulnerability and also exposed to medium or higher severe weather events.

BUILT ENVIRONMENT	

About 47% of the total state general building stock is located in areas with medium or higher severe weather exposure.

CRITICAL INFRASTRUCTURE	HIGH

62% of the critical infrastructure facilities are located in areas exposed to medium or higher severe weather events. It is likely that the risk posed by this hazard to these facilities is limited due to stringent building standards.

STATE FACILITIES	

55% of state-owned facilities are located in areas exposed to medium or higher severe weather events.
45% of the state-leased facilities are located in areas exposed to medium or higher severe weather events.

FIRST RESPONDERS	HIGH

60% of the fire stations are located in areas exposed to medium or higher severe weather events; 55% of the law enforcement facilities are located in areas exposed to medium or higher severe weather events; 55% of the emergency medical service (EMS) facilities are located in areas exposed to medium or higher severe weather events. However, sever weather events are unlikely to cause major damage to these structures because of the higher standard of building codes associated with these facilities.

ECONOMIC CONSEQUENCES	HIGH

Counties ranked medium or higher on WaSRI-SW account for 80% of real state gross domestic product (GDP).

ENVIRONMENTAL IMPACTS	LOW

Severe weather events are a part of the natural climatic cycle. As such, these events play an important role in maintenance and sustenance of local biodiversity. Only major severe weather events will result in negative impact of the local environmental resources. These too are likely to be within the overall regenerative capacity of the local environment.

Hazard Description

A severe storm is an atmospheric disturbance that results in one or more of the following phenomena: severe/high winds, hail, lightning, tornadoes and significant snowfall, ice or freezing rain (winter weather). These phenomena are defined by the National Weather Service as:

- **Severe/High Winds** – Sustained wind speeds of 40 mph or greater lasting for one hour or longer, or winds of 58 mph or greater for any duration, not caused by thunderstorms.
- **Hail** – Showery precipitation in the form of irregular pellets or balls of ice more than five millimeters in diameter, falling from a cumulonimbus cloud.
- **Lightning** – A visible electrical discharge produced by a thunderstorm. The discharge may occur within or between clouds, between the cloud and air, between a cloud and the ground or between the ground and a cloud.
- **Tornado** – A violently rotating column of air, usually pendant to a cumulonimbus cloud, with circulation reaching the ground. It nearly always starts as a funnel cloud and may be accompanied by a loud rotating noise. On a local scale, it is the most destructive of all atmospheric phenomena.
- **Winter weather**: Significant snowfall, ice and/or freezing rain; the quantity of precipitation varies by elevation. Heavy snowfall is four inches or more in a 12-hour period, or six or more inches in a 24-hour period in non-mountainous areas; and 12 inches or more in a 12-hour period or 18 inches or more in a 24-hour period in mountainous areas.

Severe Weather Hazard Location, Extent and Magnitude

As a result of its location and topography, all areas of Washington are vulnerable to severe weather events. The location of the state of Washington on the windward coast in mid-latitudes combines climatic elements of a predominantly marine-type climate characteristic of the area west of the Cascade Mountains with the dry climate in the area east of the Cascade Mountains. The state’s climate is impacted by two significant factors:

- *Mountains*: The Olympic Mountains and the Cascade Mountains affect rainfall. The first major release of rain occurs along the western slopes of the Olympics, and the second is along the western slopes of the Cascade Range. Additionally, the Cascades are a topographic and climatic barrier. Air warms and dries as it descends along the eastern slopes of the Cascades, resulting in near desert conditions in the lowest section of the Columbia Basin in Eastern Washington. Another lifting of the air occurs as it flows eastward from the lowest elevations of the Columbia Basin toward the Rocky Mountains. This results in a gradual increase in precipitation in the higher elevations along the northern and eastern borders of the state.
- *Location and intensity of semi-permanent high and low-pressure areas over the North Pacific Ocean:* During the summer and fall, circulation of air around a high-pressure area over the North Pacific brings a prevailing westerly and northwesterly flow of comparatively dry, cool

> and stable air into the Pacific Northwest. As the air moves inland, it becomes warmer and drier, resulting in a dry season. In the winter and spring, the high pressure resides further south while low pressure prevails in the Northeast Pacific. Circulation of air around both pressure centers brings a prevailing southwesterly and westerly flow of mild, moist air into the Pacific Northwest. Condensation occurs as the air moves inland over the cooler land and rises along the windward slopes of the mountains. This results in a wet season beginning in late October or November, reaching a peak in winter, gradually decreasing by late spring.

West of the Cascade Mountains, summers are cool and relatively dry while winters are mild, wet and generally cloudy. Generally, in the interior valleys, measurable rainfall occurs on 150 days each year and on 190 days in the mountains and along the coast. Thunderstorms over the lower elevations occur up to 10 days each year and over the mountains up to 15 days. Damaging hailstorms rarely occur in most localities of western Washington. During July and August, the driest months, two to four weeks can pass with only a few showers; however, in December and January, the wettest months, precipitation is frequently recorded on 20 to 25 days or more each month.

The range in annual precipitation is from about 20 inches in an area northeast of the Olympic Mountains to 150 inches along the southwestern slopes of these mountains. Snowfall is light in the lower elevations and heavy in the mountains. During the wet season, rainfall is usually of light to moderate intensity and continuous over a period of time, rather than heavy downpours for brief periods; heavier intensities occur along the windward slopes of the mountains.

The strongest winds are generally from the south or southwest and occur during the fall and winter. In interior valleys, sustained wind velocities usually reach 40 to 50 mph each winter, and 75 to 90 mph a few times every 50 years. The highest summer and lowest winter temperatures generally occur during periods of offshore easterly winds.

The climate east of the Cascade Mountains has characteristics of both continental and marine climates. Summers are warmer, winters are colder, and precipitation is less than in Western Washington. Extremes in both summer and winter temperatures generally occur when air from the continent influences the inland basin.

In the driest areas, rainfall occurs about 70 days each year in the lowland and about 120 days in the higher elevations near the eastern border and along the eastern slopes of the Cascades. Annual precipitation ranges from seven to nine inches near the confluence of the Snake and Columbia Rivers in the Tri-Cities area, 15 to 30 inches along the eastern border and 75 to 90 inches near the summit of the Cascade Mountains. During July and August, four to eight weeks can pass with only a few scattered showers. Thunderstorms, most as isolated cells, occur on one to three days each month from April through September. A few damaging hailstorms are reported each summer.

During the coldest months, freezing drizzle occasionally occurs, as does a Chinook wind that produces a rapid rise in temperature. During most of the year, the prevailing wind is from the southwest or west. The frequency of northeasterly winds is greatest in the fall and winter. Sustained wind velocities ranging from four to 12 mph can be expected 60 to 70 percent of the time; 13 to 24 mph, 15 to 24 percent of the time; and 25 mph or higher, one to two percent of the time. The highest wind velocities are from the southwest or west and are frequently associated with rapidly moving weather systems. Extreme sustained 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.

Past Occurrences and Future Probability of Occurrence

Between 1960 and 2017 the state experienced 3,629 significant severe weather events. These severe weather events consisted of 76 percent severe wind events, 17 percent winter weather events, and the rest included lightning (three percent), hail (three percent) and tornadoes (one percent). During this period, most severe weather events were reported in King County (305), followed closely by Spokane County that experienced 290 events. Other counties that experienced at least 200 severe weather events during this time period include Jefferson, Snohomish, Pierce, Thurston, Kitsap, Mason, Clallam, Lewis, Grays Harbor, Whatcom, Skagit and Okanogan counties.

Severe Weather Events (1960 2017)

County Name	Hail	Lightning	Severe Wind	Tornado	Winter Weather	Total
Adams	9	4	108	1	25	147
Asotin	9	4	86	1	18	118
Benton	5	3	118	2	24	152
Chelan	15	8	97	0	28	148
Clallam	0	3	189	0	32	224
Clark	3	6	131	9	30	179
Columbia	7	3	81	2	21	114
Cowlitz	2	2	131	4	28	167
Douglas	6	3	105	0	26	140
Ferry	7	5	104	0	23	139
Franklin	7	4	117	3	28	159
Garfield	10	3	83	1	18	115
Grant	8	8	130	3	27	176
Grays Harbor	0	2	182	0	28	212
Island	1	3	151	1	24	180
Jefferson	0	6	238	0	38	282
King	2	33	220	5	45	305
Kitsap	0	7	193	2	39	241
Kittitas	2	4	73	0	29	108
Klickitat	1	2	98	1	29	131
Lewis	2	7	170	4	37	220
Lincoln	7	3	140	4	28	182
Mason	0	6	183	1	38	228
Okanogan	23	4	143	3	33	206
Pacific	0	1	147	2	24	174

Pend Oreille	9	3	96	0	25	133
Pierce	3	17	186	8	53	267
San Juan	0	0	112	1	26	139
Skagit	2	4	164	1	38	209
Skamania	1	1	79	1	30	112
Snohomish	2	17	209	3	43	274
Spokane	14	15	218	5	38	290
Stevens	8	3	113	5	25	154
Thurston	1	11	197	5	42	256
Wahkiakum	0	1	126	1	27	155
Walla Walla	10	8	138	3	27	186
Whatcom	2	5	168	2	34	211
Whitman	14	6	119	2	25	166
Yakima	5	6	123	1	31	166
Grand Total	197	231	5466	87	1184	7165

Cumulatively, severe weather events have resulted in over $3 billion in property damages from 1960 to 2017. Most losses were experienced in King County ($195 million) followed by Kitsap ($183 million) and Lewis ($178 million) counties. Thurston, Mason, Jefferson, Yakima, Grays Harbor and Pierce counties also experienced property damages worth more than $150 million during the same period.

Impact of Significant Severe Weather Events (1960 2017)

County Name	Number of Events	Total Property Damage (in $2016)	Total Injuries	Total Fatalities
Adams	147	$38,320,866	6	2
Asotin	118	$6,509,841	2	0
Benton	152	$7,093,883	41	5
Chelan	148	$52,196,113	35	15
Clallam	224	$145,065,720	10	10
Clark	179	$139,528,923	308	8
Columbia	114	$8,327,343	7	0
Cowlitz	167	$110,744,457	7	2
Douglas	140	$11,133,270	13	2
Ferry	139	$5,111,074	4	2
Franklin	159	$34,475,395	34	5
Garfield	115	$6,943,925	2	0
Grant	176	$37,847,509	27	6
Grays Harbor	212	$158,172,789	21	8
Island	180	$47,423,764	10	2

Jefferson	282	$163,962,821	14	3
King	305	$195,838,395	120	42
Kitsap	241	$183,068,869	49	13
Kittitas	108	$44,937,826	39	4
Klickitat	131	$5,457,996	18	4
Lewis	220	$178,071,153	31	4
Lincoln	182	$35,080,515	6	2
Mason	228	$170,066,898	13	2
Okanogan	206	$97,235,110	23	3
Pacific	174	$114,675,803	8	10
Pend Oreille	133	$6,111,550	6	3
Pierce	267	$151,727,501	50	25
San Juan	139	$32,204,541	5	2
Skagit	209	$96,413,847	46	8
Skamania	112	$48,063,324	23	1
Snohomish	274	$119,863,286	36	10
Spokane	290	$49,988,600	73	7
Stevens	154	$6,493,649	3	1
Thurston	256	$176,596,706	18	5
Wahkiakum	155	$105,527,324	2	2
Walla Walla	186	$99,465,172	21	2
Whatcom	211	$70,847,705	32	8
Whitman	166	$7,726,421	10	2
Yakima	166	$159,198,044	30	11
Grand Total	7165	$3,127,517,927	1202	237

The state of Washington has experienced several notable severe weather events including extreme winter weather, tornadoes and windstorms. The following are some of the most notable events, including both declared and non-declared disasters.

Windstorms occur more often than tornadoes in Washington and cause millions of dollars in damage with each occurrence.

- January/February 1916 - Seattle's Greatest Snowstorm: Seattle recorded its maximum snowfall ever in a 24-hour period, 21.5 inches on Feb. 1. Other parts of Western Washington received between two to four feet of snow. Winds created snow drifts as high as five feet. The event crippled the whole region; transportation systems were essentially halted. During this period, Seattle recorded snowfall of 23 inches in January and 35 inches in February, for a total of 58 inches.
- The Columbus Day Windstorm that hit the Northwest on Oct. 12, 1962. It is the greatest windstorm to strike this area and has become the windstorm of which all others are

compared. This storm was the strongest widespread non-tropical windstorm to hit the continental U.S. during the 20th century, with its effects felt from northern California to British Columbia. The storm claimed 46 lives and caused the loss of power to over 1 million homes. More than 50,000 homes were damaged costing an estimated $235 million (1962 dollars).

- Jan. 13, 1950 - The January 1950 Blizzard: 21.4 inches of snow fell in Seattle on Jan. 13 together with winds of 25-40 mph, the second greatest 24-hour snowfall was recorded. This event claimed 13 lives in the Puget Sound area. During January, 18 days with high temperatures of 32 degrees or lower were experienced. The winter of 1949-50 was the coldest winter on record in Seattle with average temperatures of 34.4 degrees. Eastern Washington, North Idaho and parts of Oregon were paralyzed. At lower elevations, snow depths ranged up to 50 inches and temperatures plunged into the negative teens and twenties. Several dozen fatalities resulted from this event.
- Washington's deadliest tornado outbreak: On April 5, 1972, a devastating F3 tornado struck the Vancouver, Washington area, killing six people and injuring 300. Washington led the nation in tornado deaths that year. The tornado swept through a grocery store, bowling alley and grade school near where Vancouver Mall is today. Approximately $50 million were reported in damages. Later that day, another F3 tornado touched down west of Spokane and an F2 tornado struck rural Stevens County. Numerous severe thunderstorms with large hail and damaging winds were reported over other areas of Eastern Washington.
- The Inauguration Day Windstorm on Jan. 20, 1993 (Federal Disaster #981) brought hurricane force winds (sustained winds or gusts of 74 mph or greater) to King, Mason, Lewis, Thurston, Snohomish, Pierce and Wahkiakum counties. This storm claimed five lives and resulted in the destruction of 52 homes and damaged an additional 249 homes and 580 businesses. Total damage resulting from this storm is estimated at $130 million.
- The most powerful windstorm since the 1993 storm occurred in December 2006 (Federal Disaster #1682). This storm brought 90 mph winds to Washington's coastline and wind gusts of up to 70 mph in the Puget Sound region. The storm also knocked out power to 1.5 million Washington residents with some not seeing electricity restored for 11 days. A federal disaster declaration was declared for all 39 of Washington's counties and estimated damages exceeded $50 million dollars.
- A windstorm on July 20, 2012 hit Okanogan and Ferry counties plus the Confederated Tribes of the Colville Reservation in Eastern Washington (Federal Disaster #DR-4083). Damage estimates were at $8.4 million for Ferry County and $1.1 million for Okanogan County.

The following is a list of the some of the notable sever weather events that have resulted in federal disaster declarations:

- Washington Severe Storms, Straight-line Winds, Flooding, Landslides, and Mudslides (DR-4249) Incident period: Nov. 12, 2015 to Nov. 21, 2015, major disaster declaration declared on Jan. 15, 2016
- Washington Severe Windstorm (DR-4242) Incident period: Aug. 29, 2015, major disaster declaration declared on Oct. 15, 2015
- Washington Severe Storm, Straight-line Winds, and Flooding (DR-4083) Incident period: July 20, 2012 to July 21, 2012, major disaster declaration declared on Sept. 25, 2012

- Washington Severe Winter Storm, Flooding, Landslides, and Mudslides (DR-4056) Incident period: Jan. 14, 2012 to Jan. 23, 2012, major disaster declaration declared on March 05, 2012
- Washington Severe Winter Storm, Flooding, Landslides, and Mudslides (DR-1963) Incident period: Jan. 11, 2011 to Jan. 21, 2011; major disaster declaration declared on March 25, 2011
- Washington Severe Winter Storm and Record and Near Record Snow (DR-1825) Incident period: Dec. 12, 2008 to Jan. 05, 2009; major disaster declaration declared on March 02, 2009
- Washington Severe Storms, Flooding, Landslides, and Mudslides (DR-1734) Incident period: Dec. 1, 2007 to Dec. 17, 2007; major Disaster declaration declared on Dec. 8, 2007
- Washington Severe Winter Storm, Landslides, and Mudslides (DR-1682) Incident period: Dec. 14, 2006 to Dec. 15, 2006; major disaster declaration declared on Feb. 14, 2007
- Washington Severe Storms, Flooding, Landslides, and Mudslides (DR-1671) Incident period: Nov. 2, 2006 to Nov. 11, 2006; major disaster declaration declared on Dec. 12, 2006
- Washington Severe Storms, Flooding, Tidal Surge, Landslides, and Mudslides (DR-1641) Incident period: Jan.27, 2006 to Feb. 4, 2006; major disaster declaration declared on May 17, 2006
- Washington SEVERE STORMS (DR-137) Incident period: Oct. 20, 1962; major disaster declaration declared on Oct. 20, 1962
- Washington Severe Storm, High Winds (DR-981) Incident period: Jan. 20, 1993 to Jan. 21, 1993; major disaster declaration declared on March 4, 1993
- Washington Severe Storms and Flooding (DR-1499) Incident period: Oct. 15, 2003 to Oct. 23, 2003; major disaster declaration declared on Nov. 7, 2003
- Washington Severe Winter Storms/Flooding (DR-1159) Incident period: Dec. 26, 1996 to Feb. 10, 1997; major disaster declaration declared on Jan. 17, 1997
- Washington Storms/High Winds/Floods (DR-1079) Incident period: Nov. 7, 1995 to Dec. 18, 1995; major disaster declaration declared on Jan. 03, 1996

All communities in Washington are vulnerable to severe weather events. Based on the past frequency of occurrence, it is likely that the state will experience multiple major severe weather events annually. Severe/high wind events and winter storms are the most likely severe weather events to occur in the state. Between 1960 and 2017, on average the state experienced 125 severe weather events annually. The median number of severe weather events in a year was 102. During the same time period, the state experienced more than 100 severe weather events annually in 29 years. In only two years have the total number of severe weather events in a year been less than 30. Thus, the probability of experiencing a severe weather event in the state is greater than one, that is at least one severe weather event is likely annually. The probability of experiencing 100 or more severe weather events in a year is estimated to be 0.51, and that of 50 or more events in a year is 0.82. Since 2000, the mean number of severe weather events experienced annually in the state is 118. It is possible that changing climatic conditions will further exacerbate the frequency and intensity of severe weather events. Based on the recent data since 2000, the increasing frequency is evident with the probability of experiencing at least 100 severe weather events in year estimated as 0.58.

Years with at least One Major Severe Weather Event (1960 2017)

Year	Total
1960	272
1961	211
1962	169
1963	90
1964	152
1965	262
1966	4
1967	362
1968	117
1969	120
1970	73
1971	327
1972	316
1973	38
1974	57
1975	271
1976	41
1977	32
1978	54
1979	32
1980	47
1981	49
1982	95
1983	48
1984	9
1985	55
1986	89
1987	120
1988	120
1989	111
1990	359
1991	170
1992	286
1993	147
1994	42
1995	64

1996	62
1997	88
1998	51
1999	141
2000	118
2001	131
2002	102
2003	128
2004	92
2005	69
2006	186
2007	138
2008	162
2009	90
2010	146
2011	72
2012	136
2013	94
2014	173
2015	90
2016	85
Grand Total	7165

The frequency, duration and intensity of extreme heat is expected to increase in Washington state. This will in turn increase other weather extremes including severe/high winds, hail, lightning, tornados and winter storms.

Although severe weather events can be thought as a natural climatic cycle, since the last ice age at least, their occurrence has been within a relatively narrow band, and the sun’s energy that drives all weather has been relatively constant. However, global warming is changing this historic predictability – the reliance on stationarity is ending.

Relationship to other Hazards

Rainfall, hail and snowfall from storms influence flooding, where rainfall amount, intensity and duration can correlate with the impacts of a flood event. Rain-on-snow events can further exacerbate these types of events. This flooding can also then increase the likelihood for dam, levee and canal failures. Precipitation, as well as the associated freeze and thaw cycles that severe weather events can create, are also a major cause of landslides through a number of mediating geomorphological mechanisms. This is also true for avalanches, where snow-loading or rain-on-snow events can trigger a slide. High winds can damage numerous infrastructural facilities and networks which can cripple the communities impacted.

High winds can also cause dust storms. Several dust storms have occurred in the past years, such as the Oct. 4, 2009 and May 3, 2010 events in Eastern Washington. In 2009, visibility dropped to zero in parts of Eastern Washington as a large dust storm blew through. The storm brought strong winds gusting to 43 mph in places that propelled the dust across the southeast corner of the state. After numerous multi-vehicle accidents, sections of Interstate 90 near Moses Lake and several local roads had to be closed for several hours. Dryland farmers rely entirely on rainfall to sustain their crops, and as a result, do many things to preserve moisture in the soil. Some of these practices—leaving a field fallow after harvest to allow water to build in the soil for a year or covering the field with dry soil to prevent underlying moisture from evaporating—make dryland agriculture very prone to dust storms. These fields are likely either fallow or newly planted, probably with winter wheat, a common dryland crop in Eastern Washington. In 2010, dust storms were caused by dust rising from farmland in Central Washington where crops were not yet growing. The winds were blowing at 40 mph. The winds blew the dust across the state, forcing several roads to close because of low visibility. No events have been reported since the 2010 event. However, continuing climate change may make Washington more vulnerable to dust storms.

Severe storms also increase transportation-related accidents, which can result in hazardous material events. Ice forming on power or communication lines, in extreme cases, could lead to energy shortages and cyber disruptions. Cold weather is also tied to increased illness, which could influence the chances of a pandemic event.

There are also beneficial relationships between severe storms and other hazards. Precipitation caused by severe storms can decrease the susceptibility to wildfire events. Similarly, long-term or repeat precipitation events can also help to lessen drought conditions.

Severe Weather Risk Assessment

The severe weather risk assessment for each of the census tracts in Washington based on cumulative hazard risk from hail, lightning, thunderstorms, tornadoes, wind and winter weather events.

Hail hazard values were derived from the National Oceanic and Atmospheric Administration’s (NOAA) Storm Prediction Center data; hail hazard values are the maximum number of hail storms recorded in a given census tract between 1986 and 2016. These were ranked on a scale of 1 to 5 (1-low, 2- medium-low, 3- medium, 4-medium-high, and 5- high) based on z-score transformation (standard deviations from the mean) for each census tract (Figure S1).

Lightning hazard values were derived from gridded summaries of Vaisala National Lightning Detection Network flash observations; lighting hazard values are the maximum number of cloud-to-ground lightning flashes observed in a census tract between 1991 and November 2016. These were ranked on a scale of 1 to 5 (1-low, 2- medium-low, 3- medium, 4-medium-high, and 5- high) based on z-score transformation (standard deviations from the mean) for each census tract (Figure S2).

Severe wind hazard values were derived from NOAA's Storm Prediction Center data; severe wind hazard values are the maximum number of strong wind events recorded in a given census tract between 1986 and 2016. These were ranked on a scale of 1 to 5 (1-low, 2- medium-low, 3- medium, 4-medium-high, and 5- high) based on z-score transformation (standard deviations from the mean) for each census tract (Figure S3).

Tornado hazard values were derived from NOAA's Storm Prediction Center data; tornado hazard values are the maximum number of tornado touchdowns and paths recorded in a given census tract between 1986 and 2016. These were ranked on a scale of 1 to 5 (1-low, 2- medium-low, 3- medium, 4-medium-high, and 5- high) based on z-score transformation (standard deviations from the mean) for each census tract (Figure S4).

Winter hazard values derived from archived National Weather Service (NWS) alert polygons; winter hazard values are the number of NWS alert polygons related to cold waves issued inside a given census tract from 2005 to 2017. These were ranked on a scale of 1 to 5 (1-low, 2- medium-low, 3- medium, 4-medium-high, and 5- high) based on z-score transformation (standard deviations from the mean) for each census tract.

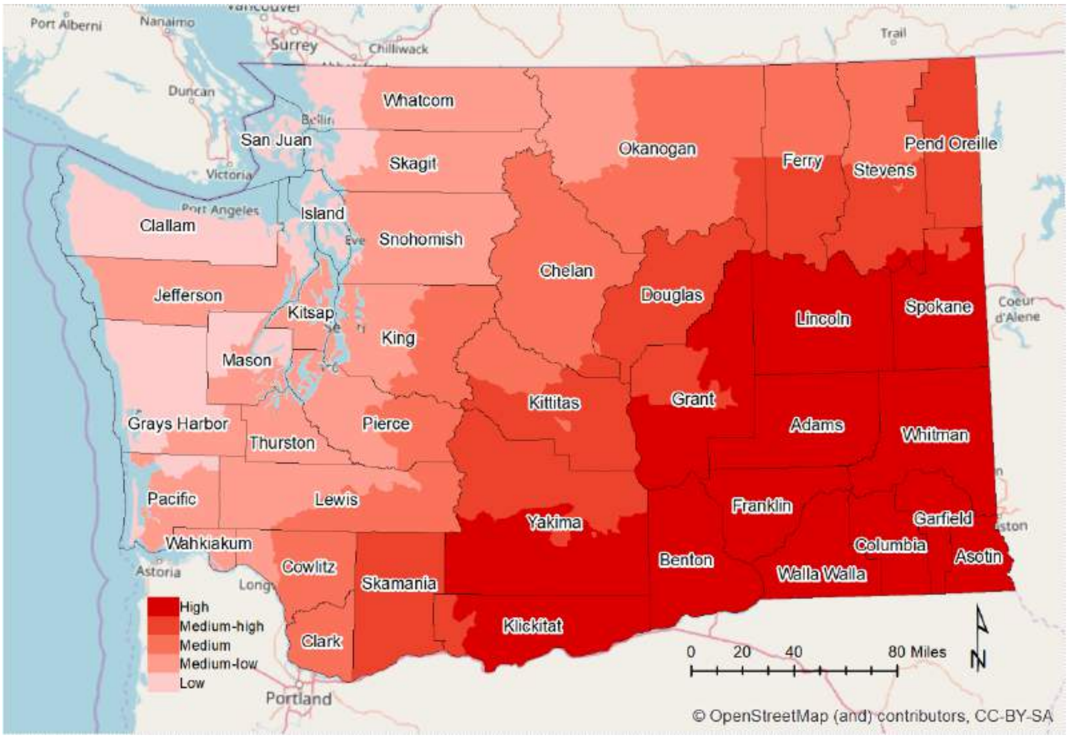

FIGURE SW 1: DISTRIBUTION OF HAIL HAZARDS

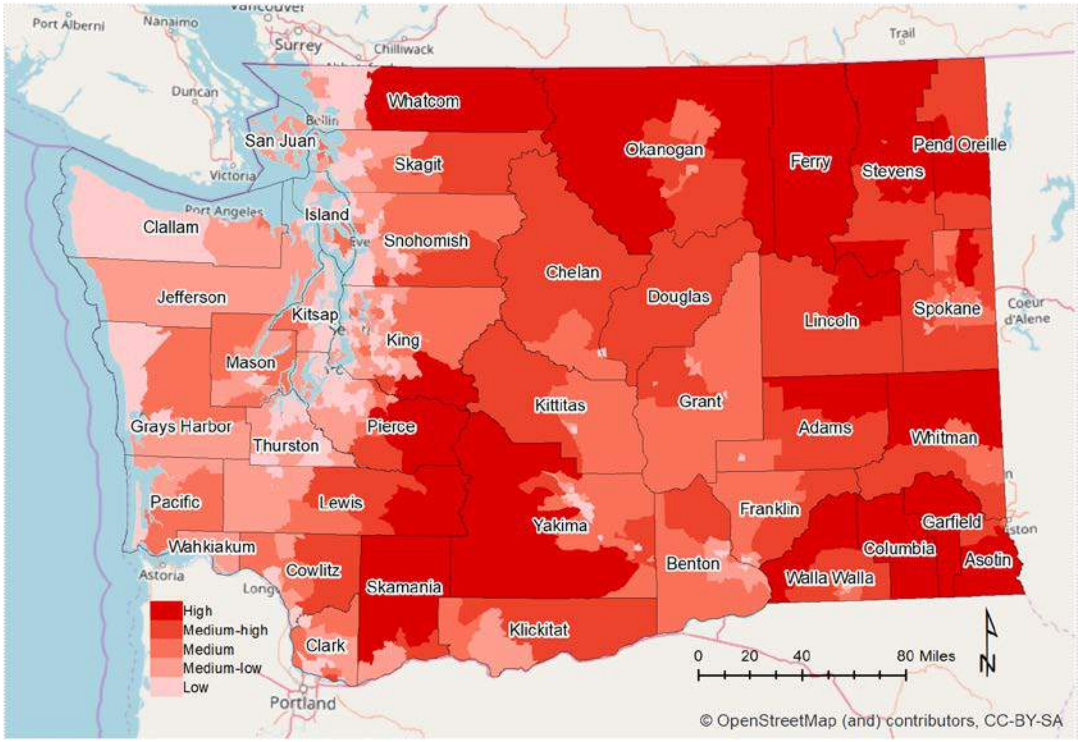

FIGURE SW 2: DISTRIBUTION OF LIGHTNING HAZARDS

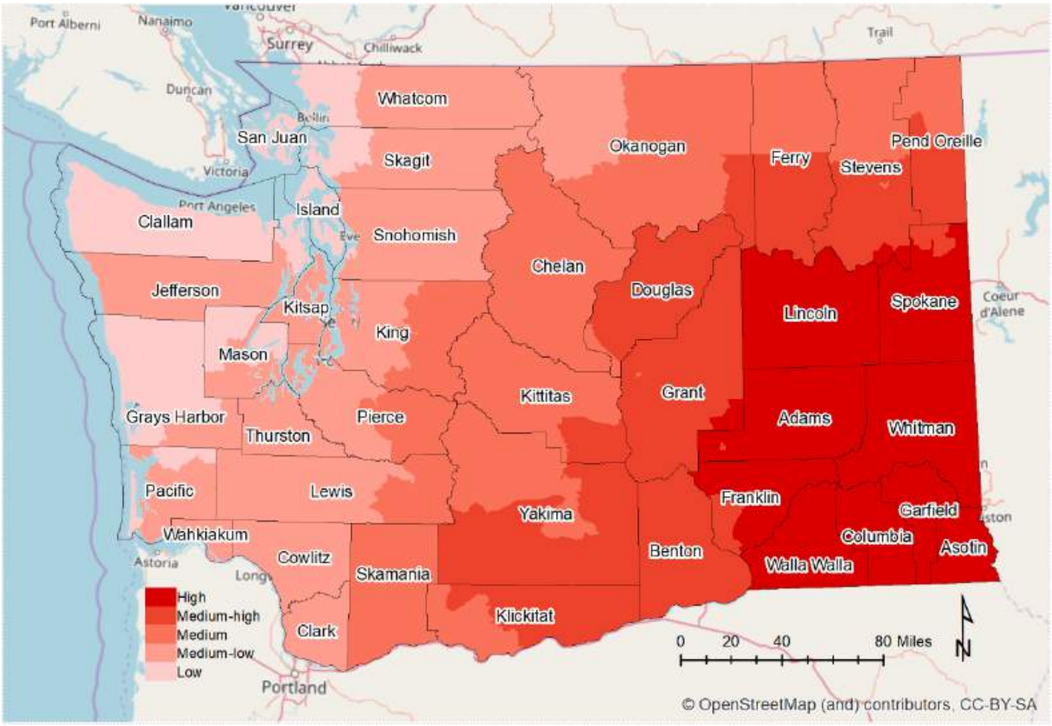

FIGURE SW 3: DISTRIBUTION OF SEVERE WIND HAZARDS

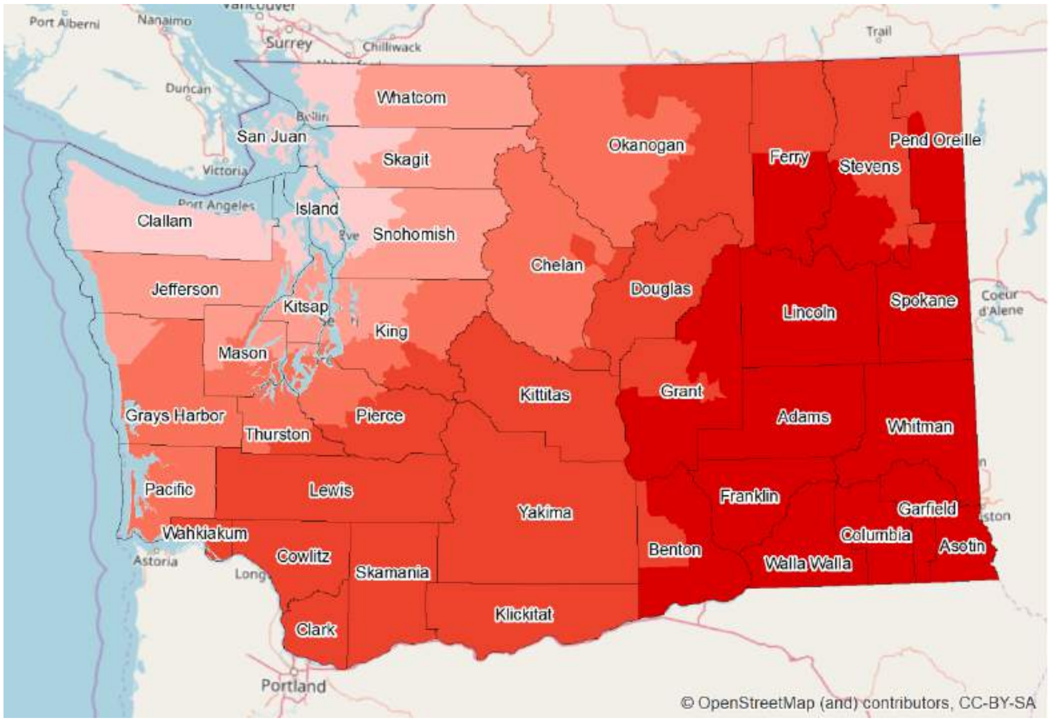

FIGURE SW 4: DISTRIBUTION OF TORNADO HAZARDS

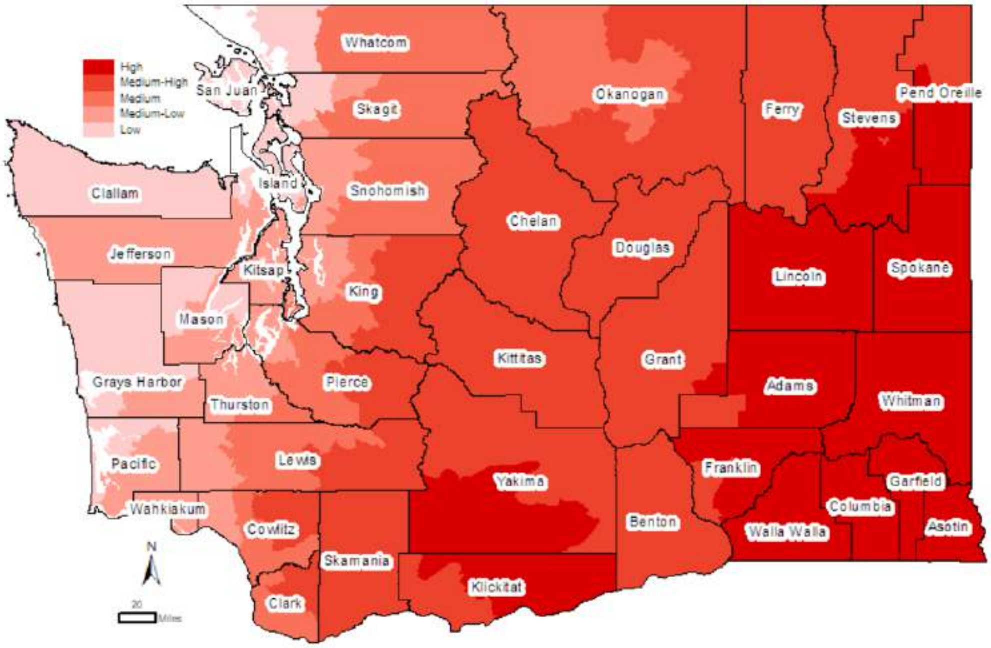

FIGURE SW 5: SEVERE WEATHER HAZARD

Area Exposure

The severe weather hazard rank zones were overlaid with the county map to estimate the area exposed to severe weather hazards (medium or higher exposure). All communities in the state are exposed to some level of severe weather hazards. Overall 80 percent of the state area is estimated to have medium or higher sever weather exposure. All census tracts in 22 counties are ranked medium or higher for severe weather exposure. This group includes all of the eastern and central counties of the state.

Percentage of County Land Area with Severe Weather Exposure

County	Medium or Higher Exposure
Adams	100.00
Asotin	100.00
Benton	100.00
Chelan	100.00
Clallam	0.00
Clark	100.00
Columbia	100.00
Cowlitz	78.10
Douglas	100.00
Ferry	100.00
Franklin	100.00
Garfield	100.00
Grant	100.00
Grays Harbor	0.00
Island	0.00
Jefferson	0.00
King	79.49
Kitsap	0.00
Kittitas	100.00
Klickitat	100.00
Lewis	77.66
Lincoln	100.00
Mason	0.00
Okanogan	100.00
Pacific	0.00
Pend Oreille	100.00
Pierce	81.34
San Juan	0.00
Skagit	68.43
Skamania	100.00
Snohomish	73.96
Spokane	100.00
Stevens	100.00
Thurston	28.05
Wahkiakum	0.00
Walla Walla	100.00

Whatcom	66.97
Whitman	100.00
Yakima	100.00
Washington State	80.50

Population Exposure

Population exposure to severe weather hazards was estimated by overlaying the hazard layer over the 2011 developed areas derived from the land cover database. The 2017 estimated population for all census tracts was allocated to respective urban areas and the overlap with hazard exposure was estimated using spatial analysis in Geographic Information System (GIS). Overall, it is estimated that 48 percent of the population resides in areas (census tracts) ranked medium or higher severe weather exposure.

Severe weather, including heat waves, wind and rain storms, hail and ice shorts are likely to increase as our climate warms.

Population Exposure to Severe Weather Hazard			
County	Total Population (2017 Estimates)	Percentage of Total State Population	Estimated County Population Exposed to Severe Weather (in % value)
Adams	19870	19870	100.00
Asotin	22290	22290	100.00
Benton	193500	193500	100.00
Chelan	76830	76830	100.00
Clallam	74240	0	0.00
Clark	471000	471000	100.00
Columbia	4100	4100	100.00
Cowlitz	105900	53133	50.17
Douglas	41420	41420	100.00
Ferry	7740	7740	100.00
Franklin	90330	90330	100.00
Garfield	2200	2200	100.00
Grant	95630	95630	100.00
Grays Harbor	72970	0	0.00
Island	82790	0	0.00
Jefferson	31360	0	0.00
King	2153700	793676	36.85
Kitsap	264300	0	0.00
Kittitas	44730	44730	100.00
Klickitat	21660	21660	100.00
Lewis	77440	47843	61.78
Lincoln	10700	10700	100.00
Mason	63190	0	0.00
Okanogan	42110	42110	100.00

Population Exposure to Severe Weather Hazard			
County	Total Population (2017 Estimates)	Percentage of Total State Population	Estimated County Population Exposed to Severe Weather (in % value)
Pacific	21250	0	0.00
Pend Oreille	13370	13370	100.00
Pierce	859400	558878	65.03
San Juan	16510	0	0.00
Skagit	124100	16416	13.23
Skamania	11690	11690	100.00
Snohomish	789400	154968	19.63
Spokane	499800	499800	100.00
Stevens	44510	44510	100.00
Thurston	276900	21624	7.81
Wahkiakum	4030	0	0.00
Walla Walla	61400	61400	100.00
Whatcom	216300	13876	6.41
Whitman	48640	48640	100.00
Yakima	253000	253000	100.00
Washington State	7310300	3450098	47.20

Vulnerable Population Exposure

The social vulnerability index was created for each of the census tracts using American Community Survey (ACS) 2011-2016 5-year data. Social vulnerability data was first overlaid with developed areas extracted from the 2011 land cover database. Tract level social vulnerability estimates were assigned to respective developed areas in each of the tracts. This data was then overlaid with the hazard layer to identify socially vulnerable developed areas that overlap with hazard exposure areas. Overall less than 10 percent of the state population is both ranked medium or higher on social vulnerability index and resides in areas ranked medium or higher for severe weather exposure. In Adams County, all of the population in areas exposed to severe weather hazards is also ranked medium or higher on social vulnerability index. In Yakima County, 54 percent of the population is ranked medium or higher on social vulnerability index and is located in areas ranked medium or higher for severe weather hazards.

In comparison to other hazards, severe weather represents a much higher risk for vulnerable population because of the surreptitious nature of impact. Many of the severe weather events that would not have a major impact on most of the population may result in catastrophic consequences for the vulnerable population. Adequate quality of shelter and access to resources to sustain oneself in severe weather conditions is important for avoiding significant negative outcomes. Therefore, communities in areas with high exposure to severe weather need to plan for adequate shelter and resources for vulnerable populations.

Vulnerable Population Exposure to Severe Weather Hazard			
County	Population (2017 Estimates)	Severe Weather Exposure (Medium or Higher Ranked)	
		Estimated Population	As % of County Population
Adams	19870	19870	100.00
Asotin	22290	0	0.00
Benton	193500	12423	6.42
Chelan	76830	3014	3.92
Clallam	74240	0	0.00
Clark	471000	15345	3.26
Columbia	4100	0	0.00
Cowlitz	105900	0	0.00
Douglas	41420	19986	48.25
Ferry	7740	0	0.00
Franklin	90330	38833	42.99
Garfield	2200	0	0.00
Grant	95630	33716	35.26
Grays Harbor	72970	0	0.00
Island	82790	0	0.00
Jefferson	31360	0	0.00
King	2153700	87817	4.08
Kitsap	264300	0	0.00
Kittitas	44730	0	0.00
Klickitat	21660	0	0.00
Lewis	77440	426	0.55
Lincoln	10700	0	0.00
Mason	63190	0	0.00
Okanogan	42110	12227	29.03
Pacific	21250	0	0.00
Pend Oreille	13370	0	0.00
Pierce	859400	22120	2.57
San Juan	16510	0	0.00
Skagit	124100	0	0.00
Skamania	11690	0	0.00
Snohomish	789400	7956	1.01
Spokane	499800	18616	3.72
Stevens	44510	2750	6.18
Thurston	276900	0	0.00
Wahkiakum	4030	0	0.00
Walla Walla	61400	8452	13.77
Whatcom	216300	0	0.00
Whitman	48640	7713	15.86
Yakima	253000	135814	53.68
Washington State	7310300	449047	6.14

Built Environment Exposure

The built environment exposure to tsunamis is calculated using the general building stock data (2014) provided by the Federal Emergency Management Agency (FEMA) that contains the building values for all structures in the census tracts. General building stock values used in this analysis are the total structure value of all buildings (except agricultural) in each census tract in 2014 dollars. Building values for all occupancy types were summed for each census tract using only structure values (not content values) and assigned to the developed areas within each tract. These maps were then overlaid on the hazard layer to estimate the general building stock value within the hazard exposure areas. Individual tract level estimates were aggregated to create the county level estimates. All of the county general building stock located in 22 counties ranked medium or higher for severe weather exposure is exposed to severe weather hazards. The general building stock in these counties constitutes 29 percent of the total state general building stock. Overall, 47 percent of the state building stock is expected to be located in areas with medium or higher severe weather exposure.

It is expected that most of the structure built up to the local building code are likely to withstand a majority of severe weather events. Physically vulnerable structures in areas exposed to severe weather events will likely require physical renovation to keep them from being negatively impacted by the severe weather events.

Climate change will increase the possibility of additional building being exposed and existing exposed building being impacted more often.

Built Environment Exposure to Severe Weather Hazards

County	Total Value of General Building Stock (2014)	Exposed to Severe Weather (Medium or Higher)	
		Total Value of General Building Stock (2014)	Percent of Total County General Building Stock (2014)
Adams	$253,615	$253,615	100.00
Asotin	$1,061,235	$1,061,235	100.00
Benton	$6,529,565	$6,529,564	100.00
Chelan	$1,573,417	$1,573,417	100.00
Clallam	$2,427,219	$0	0.00
Clark	$32,074,170	$32,074,166	100.00
Columbia	$533	$533	100.00
Cowlitz	$4,992,730	$2,504,981	50.17
Douglas	$1,211,949	$1,211,949	100.00
Ferry	$1,521	$1,521	99.99
Franklin	$1,867,499	$1,867,499	100.00
Garfield	$437	$437	100.00
Grant	$583,022	$583,022	100.00
Grays Harbor	$1,162,104	$0	0.00
Island	$2,895,464	$0	0.00
Jefferson	$1,137,144	$0	0.00
King	$362,698,022	$133,660,607	36.85

Built Environment Exposure to Severe Weather Hazards

County	Total Value of General Building Stock (2014)	Exposed to Severe Weather (Medium or Higher)	
		Total Value of General Building Stock (2014)	Percent of Total County General Building Stock (2014)
Kitsap	$17,267,166	$0	0.00
Kittitas	$530,126	$530,126	100.00
Klickitat	$4,479	$4,479	100.00
Lewis	$1,402,914	$866,734	61.78
Lincoln	$87,198	$87,198	100.00
Mason	$608,531	$0	0.00
Okanogan	$59,252	$59,252	100.00
Pacific	$125,715	$0	0.00
Pend Oreille	$8,310	$8,310	100.00
Pierce	$62,547,883	$40,675,665	65.03
San Juan	$225,856	$0	0.00
Skagit	$5,389,339	$712,889	13.23
Skamania	$17,391	$17,391	100.00
Snohomish	$52,406,666	$10,288,015	19.63
Spokane	$31,281,088	$31,281,084	100.00
Stevens	$325,218	$325,218	100.00
Thurston	$9,798,392	$765,184	7.81
Wahkiakum	$1,649	$0	0.00
Walla Walla	$3,061,065	$3,061,065	100.00
Whatcom	$15,241,051	$977,708	6.41
Whitman	$1,385,430	$1,385,430	100.00
Yakima	$7,986,979	$7,986,978	100.00
Washington State	$630,231,344	$280,355,272	47.20

All dollar amounts in multiples of ‘0000.

Critical Infrastructure Exposure

Critical infrastructure facilities that lie within the hazard impact areas will be directly impacted. While the nature and degree of impact will largely depend on the size of the severe weather event and the physical details of the facility, spatial overlay analysis can enable prioritization of site specific hazard mitigation studies. Location of 12 critical infrastructure facilities including airports (23), communication towers (16097), dams (268), education facilities (5331), electric substations (1392), hospitals (147), power plants (146), public transit stations (60), railroad bridges (1619),railway stations (317), urgent care facilities (113) and weather radar stations (two), were derived from the Homeland Security Foundation Level Database (HIFLD). This data was overlaid with the hazard zones to identify facilities located in hazard areas. This analysis refers to point data and not critical infrastructure represented by networks such as roads and rail corridors. Severe weather events will undoubtedly impact transportation corridors and other infrastructure networks. However, due to data limitations this analysis of infrastructure networks has not been considered in this analysis.

More than 60 percent of critical infrastructure facilities in the state are located in areas with medium or higher severe weather exposure. 22 counties with medium or higher severe weather exposure are estimated to have 6,530 facilities that are exposed to severe weather hazards. While these figures represent a high level of exposure, many of these facilities are expected to be built in a manner to withstand most local severe weather events. However, it is expected that intense severe weather events may result in loss of function and accessibility to many of these facilities. Therefore, local level assessments are necessary to ensure continued usability of these facilities during severe weather events.

Critical Infrastructure Exposure

County	Number of Critical Infrastructure Facilities	In areas with Medium or Higher Severe Weather Exposure	
		Number of Critical Infrastructure Facilities	Percent of Critical Infrastructure Facilities
Adams	206	206	100.00
Asotin	81	81	100.00
Benton	664	664	100.00
Chelan	507	507	100.00
Clallam	273	0	0.00
Clark	490	490	100.00
Columbia	88	88	100.00
Cowlitz	474	238	50.21
Douglas	290	290	100.00
Ferry	83	83	100.00
Franklin	270	270	100.00
Garfield	89	89	100.00
Grant	501	501	100.00
Grays Harbor	377	0	0.00
Island	104	0	0.00
Jefferson	197	0	0.00
King	2761	1033	37.41
Kitsap	451	0	0.00
Kittitas	303	303	100.00
Klickitat	322	322	100.00
Lewis	374	208	55.61
Lincoln	237	237	100.00
Mason	152	0	0.00
Okanogan	359	359	100.00
Pacific	152	0	0.00
Pend Oreille	69	69	100.00
Pierce	1130	845	74.78
San Juan	98	0	0.00
Skagit	474	106	22.36
Skamania	145	145	100.00
Snohomish	787	228	28.97
Spokane	933	933	100.00
Stevens	211	211	100.00

Thurston	462	41	8.87
Wahkiakum	17	0	0.00
Walla Walla	273	273	100.00
Whatcom	613	110	17.94
Whitman	409	409	100.00
Yakima	601	601	100.00
Washington State	16027	9940	62.02

State Operations and Facilities Exposure

The list of state-owned (9,415) and leased facilities (1,039) was obtained from 2017 facilities inventory system report produced by Office of Financial Management (detailed list included in Appendix). These facilities were geo-located based on the addresses provided in the facilities inventory report and then overlaid with tsunami hazard layer.

It is estimated that less than 54 percent of the state-owned facilities and about 44.42 percent state-leased facilities are located in areas ranked medium or higher for severe weather exposure. These include 3,748 state-owned and 367 state-leased facilities located in 22 counties with medium or higher severe weather exposure. In this case too, it is expected that these facilities have been built taking into account the local severe weather conditions and will likely withstand the impact of most severe weather events. The main concern to these facilities will likely be in terms of accessibility and continuation of day to day functions.

Climate change will increase the frequency of severe events there by increasing the likelihood of critical facility exposure, along with the interruptions of operations.

State Owned and Leased Facilities Exposure						
County	State Owned Facilities	State Leased Facilities	In areas with Medium or Higher Severe Weather Exposure			
			State Owned Facilities	Percent of State Owned Facilities	State Leased Facilities	Percent of State Leased Facilities
Adams	64	1	64	100.00	1	100.00
Asotin	90	6	90	100.00	6	100.00
Benton	159	30	159	100.00	30	100.00
Chelan	192	22	192	100.00	22	100.00
Clallam	183	12	0	0.00	0	0.00
Clark	229	23	229	100.00	23	100.00
Columbia	75	1	75	100.00	1	100.00
Cowlitz	128	18	71	55.20	8	44.44
Douglas	42	10	42	100.00	10	100.00
Ferry	32	3	32	100.00	3	100.00
Franklin	160	9	160	100.00	9	100.00
Garfield	21	0	21	100.00	0	0.00
Grant	252	15	252	100.00	15	100.00
Grays Harbor	224	13	0	0.00	0	0.00

Island	269	6	0	0.00	0	0.00
Jefferson	394	5	0	0.00	0	0.00
King	1120	226	442	39.43	31	13.72
Kitsap	269	15	0	0.00	0	0.00
Kittitas	348	11	348	100.00	11	100.00
Klickitat	110	10	110	100.00	10	100.00
Lewis	163	13	109	67.11	11	84.62
Lincoln	58	0	58	100.00	0	0.00
Mason	244	7	0	0.00	0	0.00
Okanogan	179	10	179	100.00	10	100.00
Pacific	233	6	0	0.00	0	0.00
Pend Oreille	18	5	18	100.00	5	100.00
Pierce	865	54	562	65.00	34	62.96
San Juan	282	5	0	0.00	0	0.00
Skagit	286	15	44	15.46	0	0.00
Skamania	64	2	64	100.00	2	100.00
Snohomish	270	71	58	21.30	7	9.86
Spokane	571	121	571	100.00	121	100.00
Stevens	65	7	65	100.00	7	100.00
Thurston	431	166	43	9.92	0	0.00
Wahkiakum	22	0	0	0.00	0	0.00
Walla Walla	159	11	159	100.00	11	100.00
Whatcom	283	32	23	8.10	0	0.00
Whitman	566	9	566	100.00	9	100.00
Yakima	294	61	294	100.00	61	100.00
Washington State	9415	1031	5099	54.16	458	44.42

First Responder Facilities Exposure

Locations of fire stations, law enforcement buildings and emergency medical service (EMS) stations in the state were identified from the Homeland Security Foundation Level Database (HIFLD). Using ESRI ArcMap geocoding services 1,268 fire stations, 332 law enforcement agencies, and 1,162 EMS stations (including those co-located with fire stations) were located on the state map. It is estimated that 58 percent of the fire stations, 54 percent of the law enforcement buildings and 54 percent of the EMS facilities are located in areas ranked medium or higher for severe weather exposure. Among all buildings, these are expected to have been built with higher building standards to often serve as shelters during severe weather events. Therefore, it is expected that severe storms do not pose a major risk to these facilities. Similar to other built facilities, the key concern for these facilities is likely to be the ability to function normally and continue service during severe weather events.

First Responder Facilities Exposure Severe Weather Exposure (Medium or Higher Ranked)									
County	Fire Station			Law Enforcement			EMS		
	Total Number of Facilities	In areas of Sever Weather Exposure		Total Number of Facilities	In areas of Severe Weather Exposure		Total Number of Facilities	In areas of Severe Weather Exposure	
		Number of facilities	Percent Facilities		Number of facilities	Percent Facilities		Number of facilities	Percent Facilities
Adams	11	11	100.00	4	4	100.00	5	5	100.00
Asotin	3	3	100.00	4	4	100.00	2	2	100.00
Benton	29	29	100.00	7	7	100.00	27	27	100.00
Chelan	30	30	100.00	3	3	100.00	21	21	100.00
Clallam	22	0	0.00	5	0	0.00	24	0	0.00
Clark	40	40	100.00	13	13	100.00	40	40	100.00
Columbia	3	3	100.00	1	1	100.00	2	2	100.00
Cowlitz	25	16	64.00	8	3	37.50	17	9	52.94
Douglas	12	12	100.00	3	3	100.00	8	8	100.00
Ferry	12	12	100.00	3	3	100.00	5	5	100.00
Franklin	20	20	100.00	7	7	100.00	15	15	100.00
Garfield	2	2	100.00	1	1	100.00	1	1	100.00
Grant	50	50	100.00	15	15	100.00	28	28	100.00
Grays Harbor	32	0	0.00	9	0	0.00	20	0	0.00
Island	10	0	0.00	4	0	0.00	9	0	0.00
Jefferson	12	0	0.00	4	0	0.00	13	0	0.00
King	159	60	37.74	60	17	28.33	161	61	37.89
Kitsap	47	0	0.00	6	0	0.00	49	0	0.00
Kittitas	33	33	100.00	6	6	100.00	33	33	100.00
Klickitat	36	36	100.00	3	3	100.00	25	25	100.00
Lewis	51	33	64.71	12	8	66.67	50	30	60.00
Lincoln	10	10	100.00	4	4	100.00	9	9	100.00
Mason	46	0	0.00	3	0	0.00	47	0	0.00
Okanogan	27	27	100.00	7	7	100.00	17	17	100.00
Pacific	16	0	0.00	5	0	0.00	10	0	0.00
Pend Oreille	18	18	100.00	1	1	100.00	16	16	100.00
Pierce	99	65	65.66	29	19	65.52	101	67	66.34
San Juan	4	0	0.00	1	0	0.00	5	0	0.00
Skagit	39	5	12.82	6	0	0.00	40	6	15.00
Skamania	3	3	100.00	2	2	100.00	3	3	100.00
Snohomish	74	15	20.27	23	3	13.04	73	15	20.55
Spokane	52	52	100.00	10	10	100.00	50	50	100.00
Stevens	34	34	100.00	6	6	100.00	27	27	100.00
Thurston	47	6	12.77	17	1	5.88	55	6	10.91
Wahkiakum	9	0	0.00	1	0	0.00	5	0	0.00
Walla Walla	21	21	100.00	3	3	100.00	20	20	100.00
Whatcom	50	6	12.00	10	0	0.00	54	6	11.11

Whitman	24	24	100.00	8	8	100.00	22	22	100.00
Yakima	56	56	100.00	18	18	100.00	53	53	100.00
Grand Total	1268	732	57.73	332	180	54.22	1162	629	54.13

Washington State Risk Index for Severe Weather (WaSRI-SW)

The severe weather risk index (WaSRI-SW) for each county is estimated as the average of the standardized rank of hazard exposure assessment for county area, population, vulnerable populations, built environment, critical infrastructure facilities, state facilities and first responder facilities. The individual exposure assessment values were categorized into five classes (1: low, 2: medium-low, 3: medium, 4: medium-high, and 5: high) using z-score transformation (standard deviations from the mean).

Classification Schema for Standardized Exposure Assessment Values	
Standard Deviation	Classification Rank
>1	High (5)
0.50 to 1.0	Medium-High (4)
0.5 to -0.5	Medium (3)
-0.5 to -1	Medium-Low (2)
< -1.0	Low (1)

The severe weather risk index (WaSRI-SW) is the mean of these individual exposure rankings. While similar assessments were also done for economic consequences (described in the next sections), these specific rankings were not included in the estimation of the landslide risk index. Economic consequence rankings were not included because of data quality limitations. Economic consequences estimates are based on overall county data. Including them in the index is likely to result in biased estimation of hazard risk. The natural environment impact assessment is limited to the environmental resources identified through national land cover dataset. Each natural hazard is associated with specific effects on the natural environment and therefore adoption of a common evaluation approach across all hazard types for environmental impacts is not appropriate. For severe weather hazard, no quantitative assessment for environmental impacts was undertaken. Instead specific outcomes related to severe weather events such as landslides and floods have been addressed in the respective hazard analysis.

Eastern counties are estimated to have the highest risk from severe weather hazards. The eight counties ranked high for severe weather risk include Okanogan, Douglas, Grant, Yakima, Adams, Franklin, Walla Walla and Whitman counties. These counties also have significant agricultural areas that are likely at higher risk from severe weather in comparison to developed areas.

Severe Weather Risk Index (WaSRI SW) and Constituent Exposure Ranks for Each County

County	Area	Population	Vulnerable Population	Built Environment	Critical Infrastructure	State Facilities	First Responder Facilities	Severe Weather Risk Index (WaSRI SW)
Adams	Medium-High	Medium-High	High	Medium-High	Medium-High	Medium-High	Medium-High	HIGH
Asotin	Medium-High	Medium-High	Medium-Low	Medium-High	Medium-High	Medium-High	Medium-High	MEDIUM
Benton	Medium-High	Medium-High	Medium-High	Medium-High	Medium-High	Medium-High	Medium-High	MEDIUM-HIGH
Chelan	Medium-High	Medium-High	Medium-High	Medium-High	Medium-High	Medium-High	Medium-High	MEDIUM-HIGH
Clallam	Low	Low	Medium-Low	Low	Low	Low	Low	LOW
Clark	Medium-High	Medium-High	Medium-High	Medium-High	Medium-High	Medium-High	Medium-High	MEDIUM-HIGH
Columbia	Medium-High	Medium-High	Medium-Low	Medium-High	Medium-High	Medium-High	Medium-High	MEDIUM
Cowlitz	Medium-Low	Medium-Low	Medium-Low	Medium-Low	Medium-Low	Medium-Low	Medium-Low	MEDIUM-LOW
Douglas	Medium-High	Medium-High	High	Medium-High	Medium-High	Medium-High	Medium-High	HIGH
Ferry	Medium-High	Medium	Medium-Low	Medium	Medium-High	Medium-High	Medium-High	MEDIUM
Franklin	Medium-High	Medium-High	High	Medium-High	Medium-High	Medium-High	Medium-High	HIGH
Garfield	Medium-High	Medium-High	Medium-Low	Medium-High	Medium-High	Medium-High	Medium-High	MEDIUM
Grant	Medium-High	Medium-High	High	Medium-High	Medium-High	Medium-High	Medium-High	HIGH
Grays Harbor	Low	Low	Medium-Low	Low	Low	Low	Low	LOW
Island	Low	Low	Medium-Low	Low	Low	Low	Low	LOW
Jefferson	Low	Low	Medium-Low	Low	Low	Low	Low	LOW
King	Medium	Medium	Medium-High	Medium	Medium-Low	Medium-Low	Medium-Low	MEDIUM
Kitsap	Low	Low	Medium-Low	Low	Low	Low	Low	LOW
Kittitas	Medium-High	Medium-High	Medium-Low	Medium-High	Medium-High	Medium-High	Medium-High	MEDIUM
Klickitat	Medium-High	Medium-High	Medium-Low	Medium-High	Medium-High	Medium-High	Medium-High	MEDIUM
Lewis	Medium-Low	Medium	Medium	Medium	Medium	Medium	Medium	MEDIUM
Lincoln	Medium-High	Medium-High	Medium-Low	Medium-High	Medium-High	Medium-High	Medium-High	MEDIUM

Severe Weather Risk Index (WaSRI SW) and Constituent Exposure Ranks for Each County

County	Area	Population	Vulnerable Population	Built Environment	Critical Infrastructure	State Facilities	First Responder Facilities	Severe Weather Risk Index (WaSRI SW)
Mason	Low	Low	Medium-Low	Low	Low	Low	Low	LOW
Okanogan	Medium-High	Medium-High	High	Medium-High	Medium-High	Medium-High	Medium-High	HIGH
Pacific	Low	Low	Medium-Low	Low	Low	Low	Low	LOW
Pend Oreille	Medium-High	Medium-High	Medium-Low	Medium-High	Medium-High	Medium-High	Medium-High	MEDIUM
Pierce	Medium	Medium	Medium-High	Medium	Medium	Medium	Medium	MEDIUM
San Juan	Low	Low	Medium-Low	Low	Low	Low	Low	LOW
Skagit	Medium-Low	Medium-Low	Medium-Low	Medium-Low	Medium-Low	Medium-Low	Medium-Low	MEDIUM-LOW
Skamania	Medium-High	Medium-High	Medium-Low	Medium-High	Medium-High	Medium-High	Medium-High	MEDIUM
Snohomish	Medium-Low	Medium-Low	Medium-High	Medium-Low	Medium-Low	Medium-Low	Medium-Low	MEDIUM-LOW
Spokane	Medium-High	Medium-High	Medium-High	Medium-High	Medium-High	Medium-High	Medium-High	MEDIUM-HIGH
Stevens	Medium-High	Medium-High	Medium-High	Medium-High	Medium-High	Medium-High	Medium-High	MEDIUM-HIGH
Thurston	Medium-Low	Medium-Low	Medium-Low	Medium-Low	Medium-Low	Medium-Low	Medium-Low	MEDIUM-LOW
Wahkiakum	Low	Low	Medium-Low	Low	Low	Low	Low	LOW
Walla Walla	Medium-High	Medium-High	High	Medium-High	Medium-High	Medium-High	Medium-High	HIGH
Whatcom	Medium-Low	Medium-Low	Medium-Low	Medium-Low	Medium-Low	Medium-Low	Medium-Low	MEDIUM-LOW
Whitman	Medium-High	Medium-High	High	Medium-High	Medium-High	Medium-High	Medium-High	HIGH
Yakima	Medium-High	Medium-High	High	Medium-High	Medium-High	Medium-High	Medium-High	HIGH

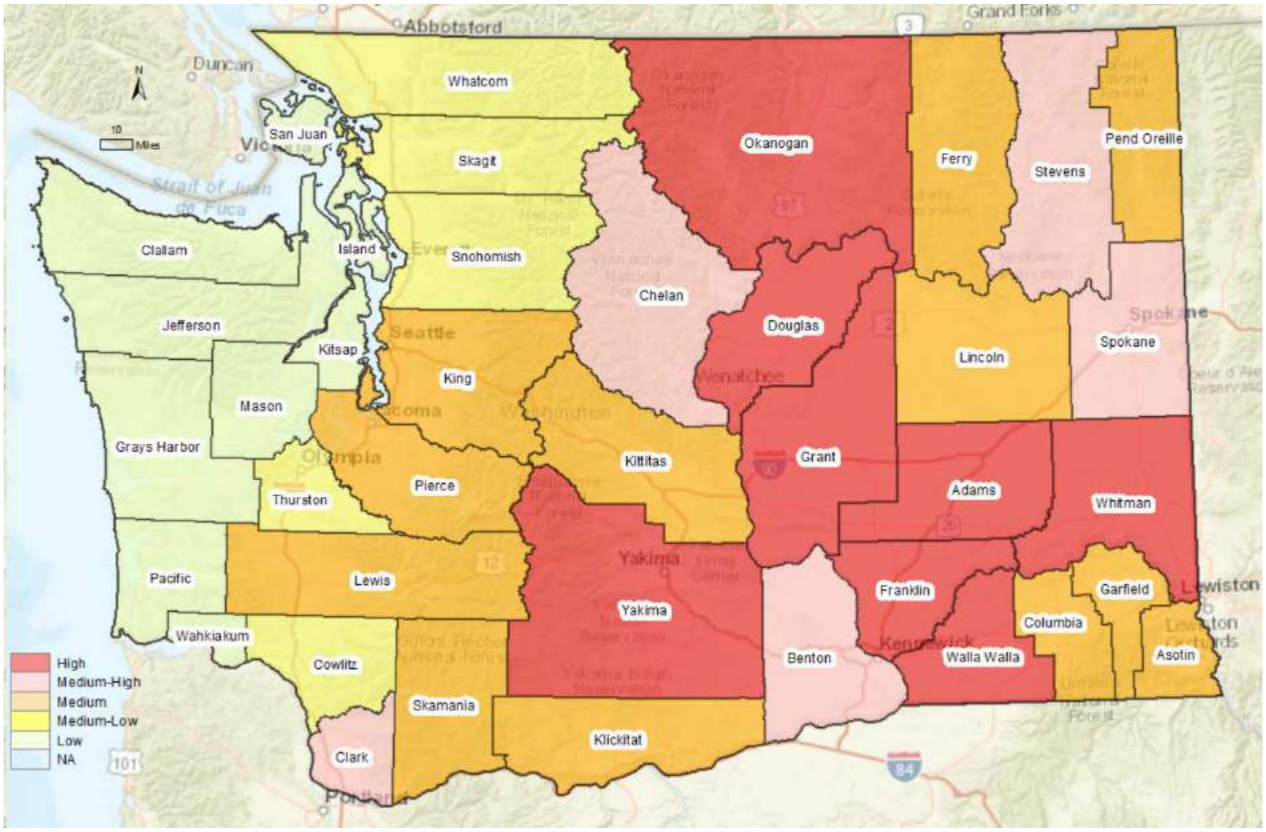

Figure SW 6: Severe Weather Risk Index (WaSRI-SW)

Economic Consequences

The economic activity data was derived from National Association of Counties. This dataset provides the county level estimates of Gross Domestic Product (GDP) for 2016. The counties ranked medium or higher on the severe weather risk index account for 80 percent of the state GDP. This includes King and Pierce counties, which are the top two contributors to state GDP. However, it is expected that economic consequence of severe weather events is likely to be much more significant in agricultural areas in the eastern part of the state. In these regions, major economic consequences are likely to be due to loss of crop and farm productivity. Whereas, in the urban areas, most of the economic consequence are likely to be in form of lost productivity and minor damages.

Economic losses will increase with climate change. Increases in severe weather incidences may result in more frequency and longer business interruptions and capital losses.

Drought Risk (WaSRI D) and County GDP 2016

County	Drought Risk Index (WaSRI D)	GDP 2016 (in Mil.)
Adams	HIGH	$746.07
Asotin	MEDIUM	$618.43
Benton	MEDIUM-HIGH	$10,627.85
Chelan	MEDIUM-HIGH	$4,363.01
Clallam	LOW	$2,573.06
Clark	MEDIUM-HIGH	$18,682.64
Columbia	MEDIUM	$144.20
Cowlitz	MEDIUM-LOW	$4,474.88
Douglas	HIGH	$1,037.39
Ferry	MEDIUM	$198.13
Franklin	HIGH	$3,356.16
Garfield	MEDIUM	$97.44
Grant	HIGH	$3,803.65
Grays Harbor	LOW	$2,237.44
Island	LOW	$2,796.80
Jefferson	LOW	$867.23
King	MEDIUM-LOW	$230,344.61
Kitsap	LOW	$12,082.18
Kittitas	MEDIUM	$1,566.21
Klickitat	MEDIUM	$1,004.05
Lewis	MEDIUM	$2,573.06
Lincoln	MEDIUM	$347.25
Mason	LOW	$1,566.21
Okanogan	HIGH	$1,678.08
Pacific	LOW	$637.45
Pend Oreille	MEDIUM	$354.63
Pierce	MEDIUM	$41,280.80
San Juan	LOW	$602.88
Skagit	MEDIUM-LOW	$5,705.48
Skamania	MEDIUM	$218.04
Snohomish	MEDIUM-LOW	$39,378.97
Spokane	MEDIUM-HIGH	$24,723.73
Stevens	MEDIUM-HIGH	$1,111.56
Thurston	MEDIUM-LOW	$12,865.29
Wahkiakum	LOW	$93.41
Walla Walla	HIGH	$2,908.67
Whatcom	MEDIUM-LOW	$10,068.49
Whitman	HIGH	$2,237.44
Yakima	HIGH	$10,404.10

Risk to Environment

Severe weather events are a part of the natural climatic cycle. As such these events play an important role in maintenance and sustenance of local biodiversity. Climate change is a major driver impacting weather patterns and, in turn, the natural environment. For example, as there are fewer freezing days along the eastern Cascade slopes, fewer bark beetles are dying, severely stressing existing forests. Different species will fill this vacated niche. This, as with all adaption, this will benefit some and adversely impact others.

Terrorism and Cyber Terrorism Hazard Profile

Risk Summary

Frequency – An act of terrorism or violent extremism in Washington State is likely to occur annually. This is based on metrics of historical terrorism and violent extremism events—including attacks and foiled plots by designated foreign or domestic terrorist groups, or violent extremists using terror tactics in the furtherance of social, political or personal ideologies. ***Note**: With terrorist and violent extremist attacks and plots becoming more prevalent, Washington State has encountered more than 40 attempted and successful attacks in the past decade; or an average of four per year.*

People – If a terrorist attack were to occur in a densely populated city in Washington, it can be expected that 1,000 to 10,000 people could potentially be impacted. ***Note**: This is based on a worst-case scenario, where an improvised explosive device (IED) is used in an attack similar to the 2013 Boston Marathon bombing, or a complex coordinated attack (CCA), like the 2015 Paris attacks. A more likely scenario would be an active shooter or vehicle attack, where less than 100 people would be impacted. The total impact of a terrorist or violent extremist event is dependent upon the actor's motivation or desired outcome, tactic used, specific location, weapon type and success of the attack.*

Property – If a large-scale attack was to occur in a densely populated city or against a critical infrastructure in Washington State, the expected damage would likely be between $500 million and $1 billion. ***Note**: This is based on a worst-case scenario, where a large IED is involved. A more likely scenario would be an active shooter or vehicle attack, causing less than $1 million in damages. The exact dollar amount incurred in any terrorist or violent extremist event is dependent upon the actor's motivation or desired outcome, tactic used, specific location, weapon type and success of the attack.*

Economy – Recent terrorist and violent extremist attacks in the U.S. have negatively affected the local economy of the cities in which they occurred. If a terrorist attack were to occur in Washington State, a less than 1 percent gross domestic product (GDP) change would be expected. ***Note**: This is based on estimated effects from previous attacks.*[i] *The psychosocial impacts, also known as the "fear factor" of an attack, would likely be a major economic factor. This can include the declined perception of local stability, hesitation of going to public places, mistrust in law enforcement and government to deter such events, and a general uneasiness in certain areas where an extremist attack has occurred.*

Environment – Although acts of terrorism and violent extremism have affected the environment in the past, the potential eradication of more than 10 percent of a species or habitat is considered to be unlikely. ***Note**: Though assessed to be of low probability, large-scale arson would increase the environmental damages exponentially; for example, the damage caused by an intentionally-set forest fire would depend on the size of the spread.*

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[i] http://visionofhumanity.org/app/uploads/2017/11/Global-Terrorism-Index-2017.pdf

Threat Type – Terrorism and violent extremism can include a broad spectrum of groups or individuals who use terror tactics (i.e., causing violence, death, damage, etc.) in the furtherance of social or political ideologies; including foreign terrorist organizations (FTOs), homegrown violent extremists (HVEs) and domestic violent extremists (see Threat Definitions.)

Table 1 Terrorism and Violent Extremism Cases in Washington	
25-Aug-2016	Melvin Thomas Neifert$^{\text{USPER}}$ – Seattle May Day incendiary device attack plot
16-Aug-2016	Daniel Rowe$^{\text{USPER}}$ – Stabbed an interracial couple outside an Olympia restaurant
01-May-2016	Wil Floyd$^{\text{USPER}}$ and 8 Anarchist Extremists – Seattle May Day firebombing and assault
06-Feb-2016	Daniel Seth Franey$^{\text{USPER}}$ – Army National Guard deserter threatened to kill Americans for ISIS
02-Jan-2016	Occupation of Oregon’s Malheur National Wildlife Refuge by armed militia group
04-Sep-2015	Unknown Anti-Abortion Extremist – Pullman Planned Parenthood firebombing attack
01-Dec-2014	Jaleel Tariq Abdul-Jabbaar$^{\text{USPER}}$ – Threatened to kill police following Ferguson events
27-Sep-2014	Unknown Earth Liberation Front (ELF) – Bulldozed Bothell BPA tower caused significant damage
18-Jul-2014	Ali Muhammad Brown$^{\text{USPER}}$ – Killed a gay couple in Seattle and a student in New Jersey
01-Jan-2014	Musab Masmari$^{\text{USPER}}$ – Failed arson of a Seattle gay nightclub’s New Year event
03-Jul-2013	Justin Miles Jasper$^{\text{USPER}}$ – Anarchist stole truck in MT to attack various WA universities
30-May-2013	Matthew Ryan Buquet$^{\text{USPER}}$ – Mailed ricin and threats to multiple government officials
26-Feb-2013	Unknown Environmental Extremist – Seattle "Green Homes" Arson caused $30,000 in damages
29-Oct-2011	Abdisalan Hussein Ali$^{\text{USPER}}$ – third American killed as Al-Shabaab suicide bomber
08-Sep-2011	Michael McCright$^{\text{USPER}}$ – Vehicular assault against U.S. Marines on I-5 in Seattle
22-Jun-2011	Abu Khalid Abdul-Latif$^{\text{USPER}}$ and Walli Mujahidh$^{\text{USPER}}$ – Foiled Seattle MEPS attack plot
09-May-2011	Joseph Brice$^{\text{USPER}}$ – Amateur IED maker posting online how-to videos in Clarkston, WA
17-Jan-2011	Kevin Harpham$^{\text{USPER}}$ – Foiled Spokane Martin Luther King Jr. Parade backpack bomb plot
22-Oct-2009	Christopher Monfort$^{\text{USPER}}$ – Murdered Seattle Police Officer and firebombed police vehicles
12-Dec-2008	Ruben Shumpert$^{\text{USPER}}$ – Ex-convict joins al-Shabaab, killed in Somalia as suicide bomber

However, another threat type includes targeted violence, whereby groups or individuals not motivated by social or political ideologies use terror tactics as a means to satisfy personal grievances. This threat type may include, but is not limited to, rampage shootings, suicide attacks, or cases of mental instability.

Table 2 Targeted Violence Cases in Washington	
13-Sep-2017	Caleb Sharpe$^{\text{USPER}}$– Opened fire at Spokane High School; killed 1 and injured 3
14-Jan-2017	Isaac Wayne Wilson$^{\text{USPER}}$ – Set fire to the Bellevue Islamic Center of Eastside
24-Sep-2016	Arcan Cetin$^{\text{USPER}}$ – Burlington Mall shooting; killed 5 before fleeing and being arrested
20-Jul-2016	Allen Christopher Ivanov$^{\text{USPER}}$ – Jealous ex opened fire at a Mukilteo house party; killed 3
09-Aug-2015	Blake Edward Heger$^{\text{USPER}}$ – Puyallup hardware store backpack bomb and knife attack plot
10-Jan-2015	John Lee$^{\text{USPER}}$ – Shot 4 in Idaho shooting spree before being captured in Pullman, WA
24-Oct-2014	Jaylen Ray Fryberg$^{\text{USPER}}$ – Shot 6 friends at Marysville High School; killed 4, injured 2, suicide
15-Oct-2014	Hans Eric Hansen$^{\text{USPER}}$ – Shooting rampage targeting police in Snohomish County
05-Jul-2014	Aaron Ybarra$^{\text{USPER}}$ – Opened fire with a shotgun at Seattle Pacific University
24-Dec-2012	Ja'mari Alexander Jones$^{\text{USPER}}$ – Opened fire at a Bellevue sports bar football party
11-Dec-2012	Jacob Tyler Roberts$^{\text{USPER}}$ – Opened fire with M4 rifle at Portland mall; killed 2, injured 1
30-May-2012	Ian Stawicki$^{\text{USPER}}$ – Opened fire at Seattle coffee shop, hijacked car, killed himself
29-Nov-2009	Maurice Clemmons$^{\text{USPER}}$ – Murdered 4 Lakewood Police Officers at a coffee shop

Probability of Future Events – It is impossible to predict the probability of future terrorist or violent extremist events; however, the frequency of such events has increased to more than annually over the last decade. Based on recent, successful terrorist and violent extremist events:

- The *most likely tactics* include: active shooter(s), vehicle attacks, stabbing/cutting, bombings and cyberattacks.
- The *least likely tactics* include: chemical, biological, radiological, and nuclear (CBRN) bombing, hijacking/skyjacking and maritime attacks.
- The *most likely targets* include: human targets (particularly military, government and law enforcement personnel), government facilities, commercial facilities (including public assembly, retail, and entertainment and sports venues) and transportation.
- The *least likely targets* include: amusement parks, bridges, museums, national monuments or icons and vessels.

Jurisdictions at Greatest Risk – Generally, terrorists target densely populated or high-profile areas. Therefore, any of Washington's major urban areas could be considered "at risk," as well as any of the State's higher profile critical infrastructure. King, Pierce, Snohomish, Clark and Spokane counties have the highest population and critical infrastructure density in the State. However, the specific motivations of terrorist and violent extremists dictate target selection, thus any location in Washington has the potential to become a target. (see Figure 1 for more)

Hazard Profile

Despite nearly two decades of robust counterterrorism and homeland security efforts, forecasting potential terrorist targets and events continues to be a difficult—if not impossible—task at the national level, as well as within Washington State. Foreign terrorist organizations (FTOs), homegrown violent extremists (HVEs), domestic terrorists and violent extremists[ii] are determinedly and concurrently employing efforts to cause harm to the U.S., its allies and its interests. The sheer volume of events, the evolution of tactics and the limited indicators presented in recent acts of terrorism against the Homeland are primary reasons Washington State is including the Terrorism Profile to its statewide Threat Mitigation Plans. This Terrorism Profile intends to outline, among other things, some of the risk factors which make Washington State a target-rich environment, and therein, identify critical focus areas for threat mitigation planning at the state and local levels.

Threat Definitions

The Federal Bureau of Investigation (FBI) defines **terrorism** as "the unlawful use of force or violence against persons or property to intimidate or coerce a government, the civilian population, or any segment thereof, in furtherance of political or social objective."[iii] The definition continues to specify terrorism as either domestic or international, based upon the origin, base and objectives of the terrorist organization, as follows:

"**International Terrorism** is the unlawful use of force or violence committed by a group or individual, who has some connection to a foreign power or whose activities transcend national boundaries, against persons or property to intimidate or coerce a government, the civilian

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[ii] For the purposes of this assessment, the term "violent extremist" will refer to all FTOs, HVEs, domestic terrorists, domestic violent extremists, and other targeted violence unless specified otherwise.

[iii] http://www.fbi.gov/about-us/investigate/terrorism/terrorism-definition

population, or any segment thereof, in furtherance of political or social objectives."[iv] *(**Examples**: 2009 attempted airliner underwear bombing, 2001 World Trade Center attacks, 2005 London train bombings, 2010 Mumbai attacks, 2010 Time Square attempted bombing, 2015 Paris complex coordinated attacks, etc.)*

"**Homegrown Violent Extremism (HVE)** is a person of any citizenship who has lived and/or operated primarily in the U.S. who advocates, is engaged in, or is preparing to engage in ideologically-motivated terrorist activities (including support to terrorism) in the furtherance of political or social objectives promoted by an FTO, but is acting independently of direction by the FTO."[v] *(**Examples**: 2009 Fort Hood shooting, 2013 Boston Marathon bombing, 2015 Chattanooga Recruiting Center shooting, 2015 San Bernardino mass shooting, 2016 Pulse Nightclub shooting, etc.)*

"**Domestic Terrorism** are acts of terrorism perpetrated by individuals and/or groups inspired by or associated with primarily designated U.S.-based movements or organizations that espouse extremist ideologies of a political, religious, social, racial or environmental nature."[vi, vii] *(**Examples**: 1995 Oklahoma City bombing, 1996 Olympic Park bombings, 2001 University of Washington firebombing, 2009 murder of an abortion physician, 2010 Hutaree Militia plots against law enforcement, etc.)*

"Domestic Violent Extremism (DVE) is encouraging, supporting or committing a violent act to achieve political, ideological, religious, social, or economic goals,"[viii] but is not associated with a designated foreign or domestic terrorist organization. Includes extremism ideologies based on religious supremacy, racial/ethnic supremacy, environmental/animal rights, political extremism and single-issue extremism (e.g., anti- abortion, law enforcement, homosexuality, immigration). *(**Examples**: 2012 Seattle May Day attacks, 2014 Austin anti-government rampage shooting, 2014 Las Vegas police officer shooting, 2015 Planned Parenthood arson, 2016 Dallas sniper attack, 2017 Charlottesville vehicle attack, etc.)*

"**Targeted Violence** is an intentional act committed by an individual or group for the purpose of (or resulting in) psychologically and/or physically affecting an organization or person associated with an organization, whereby the attacker selects a particular target prior to their violent attack." This includes hate crimes, workplace violence, rampage shootings, [non-terrorism] suicide attacks or cases of violence caused by mental instability.[ix, x] *(**Examples**: 1999 Columbine High School massacre, 2010 Austin IRS plane attack, 2015 Marysville High School shooting, 2016 Mukilteo house party shooting, 2016 Burlington mall shooting, 2017 Texas church shooting, 2017 Las Vegas mass shooting, etc.)*

"**Cyberterrorism** is the convergence of cyberspace and terrorism. It refers to unlawful attacks and threats of attack against computers, networks and the information stored therein when done to

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[iv] http://denver.fbi.gov/nfip.htm
[v] http://publicintelligence.net/wp-content/uploads/2012/05/DHS-ExtremismLexicon-3.png
[vi] https://www.fbi.gov/investigate/terrorism
[vii] https://www.gpo.gov/fdsys/pkg/PLAW-107publ56/pdf/PLAW-107publ56.pdf
[viii] https://www.fbi.gov/cve508/teen-website/what-is-violent-extremism
[ix] https://www.ncjrs.gov/pdffiles/threat.pdf
[x] http://www.theiacp.org/Portals/0/documents/pdfs/PSYCH2014_ThreatAssessment.pdf

intimidate or coerce a government or its people in furtherance of political or social objectives. A cyberterrorism attack may result in violence against persons or property, or at least cause enough harm to generate fear.[xi] *(**Examples**: 2003 Ohio nuclear power plant servers crashed by Slammer Worm, 2012-2016 al-Qa'ida calls for "electronic jihad" against U.S. critical infrastructure, 2015 U.S. Central Command social media hack and doxing of U.S. military members by "Islamic State Hacking Division", etc.)*

"Weapons of Mass Destruction (WMD) are any explosive or incendiary device, as defined in Title 18 USC, Section 921, as a bomb, grenade rocket, missile, mine or other device with a charge of more than four ounces." A WMD is further defined as "any weapon designed or intended to cause death or serious bodily injury through the release, dissemination or impact of toxic or poisonous chemicals or their precursors."[xii] *(**Examples**: 2001 anthrax attacks, 2002 dirty bomb plot, 2009 plan to shoot down military planes with missiles, 2009 Tucson chlorine chemical device attack, 2013 radiation weapon plot, etc.)*

Previous Occurrences

Prior to the attacks on September 11, 2001 (9/11), there were less than a dozen major terrorist events in Washington State. Since then, violent extremism has become commonplace, on a global and national scale, and the number of local terrorism and violent extremism cases continues to rise.[xiii] Some of the most notorious terror cases include the arrest of Ahmed Ressam, the "Millennium Bomber," in December 1999; the Earth Liberation Front (ELF) firebombing of University of Washington's (UW) horticulture center in May 2001; and the foiled Seattle Military Entrance Processing Station (MEPS) attack plot in 2011.[xiv]

Figure 16-2: *The former UW Center for Urban Horticulture building after the May 2001 firebombing.*

Writ large, the nation continues to endure a growing number of violent attacks. Within the last 10 years, there have been more than 40 terrorism, violent extremism and targeted violence cases in or with connections to the Pacific Northwest. In September 2017, the acting Homeland Security Secretary stated, "the magnitude of threats we face is equal to, and in many ways, exceeds, the period following 9/11. We are seeing a surge in terrorist activity because the fundamentals of terrorism have evolved."[xv] Those changes include everything from recruitment and the profile of individual operatives, to the types of operations and the tactics they use. "Enemies are now crowdsourcing propaganda online and promoting a do-it-yourself approach" involving the use of simple tactics against soft targets.[xvi] While enhanced security measures aim to constrain the

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[xi] http://cs.georgetown.edu/~denning/infosec/cyberterror.html

[xii] http://www.fbi.gov/hq/nsb/wmd/ wmd_home.htm

[xiii] This increase is likely due to a number of factors including, but not limited to, expansion of the definitions of terrorism and violent extremism, increased awareness and better tracking of violent extremist incidents, technology that enables the rapid spread of extremist ideology and propaganda, and an actual increase in events.

[xiv] http://crosscut.com/2008/05/30/crime-safety/14655/

[xv] file://fusionfs/FolderRedirection/kiagraham/Downloads/Testimony-Duke-2017-09-27.pdf

[xvi] http://www.washingtonexaminer.com/homeland-security-chief-elaine-duke-terror-threat-in-many-ways-exceeds-that-of-911/article/2635780

abilities of violent extremists to execute large-scale attacks, advances in technology allows them to "evade detection by plotting in virtual safe havens, radicalize new followers and recruit beyond borders."[xvii]

The WSFC is unaware of any specific or credible threats directed at targets within Washington State. However, the absence of specific information does not discount the possibility that significant criminal or terrorist activity could occur. Attacks resulting from international terrorism, domestic terrorism and significant criminal activity can manifest in numerous ways. The following attack categories—though many cases can fall into multiple categories—are the most likely methods used by terrorists and violent extremists, with notable examples of plots or attacks occurring within Washington State:

Active Shooters (Single/Multiple): An individual or group who participates in a random or systematic shooting spree demonstrating their intent to continuously harm or kill others. These situations are dynamic and evolve rapidly, demanding immediate deployment of law enforcement resources to stop the shooting and limit harm or loss of life to innocent victims.[xviii]

On September 13, 2017, Caleb Sharpe^{USPER}, a 15-year-old student, brought an AR-15 rifle and a handgun to Freeman High School and opened fire on fellow students, killing one student and wounding three others. Another student at the school told authorities that Sharpe "had long been obsessed with past school shootings"[xix] and Sharpe told police he wanted "to teach everyone a lesson about what happens when you bully others."[xx]

On September 24, 2016, Arcan Cetin^{USPER} opened fire on shoppers in Macy's at the Cascade Mall in Burlington, WA, killing five people before fleeing. Nearly 30 hours later, police arrested him in Oak Harbor, WA. Instead of Macy's, his initial target was likely the movie theater, based on his actions seen on security footage before the shooting.[xxi] On April 16, 2017, Cetin was found dead in his jail cell from apparent suicide.[xxii]

On July 30, 2016, Allen Ivanov^{USPER} opened fire at a house party in Mukilteo, WA in jealous rage after seeing a social media post by his ex-girlfriend and spotting her with another guy through the window. Ivanov returned to his car and studied the owner's manual for his new AR-15 semi-automatic rifle. Nearly two hours later, he walked back to the home and opened fire, killing three, including his ex, and wounding a fourth.[xxiii]

[xvii] file://fusionfs/FolderRedirection/kiagraham/Downloads/Testimony-Duke-2017-09-27.pdf

[xviii] http://www.ctcd.edu/police/pd_response_active_shooter.pdf

[xix] https://heavy.com/news/2017/09/caleb-sharpe-freeman-high-school-shooting-suspect-bullying/

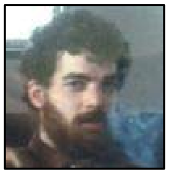
[xx] https://www.nbcnews.com/news/us-news/washington-school-shooting-suspect-wanted-teach-bullies-lesson-n801346

[xxi] http://www.king5.com/article/news/local/amc-loews-may-have-been-a-planned-target-for-cascade-mall-shooting-police-say/355181940

[xxii] http://komonews.com/news/local/accused-burlington-mall-shooter-dead

[xxiii] http://www.seattletimes.com/seattle-news/crime/document-mukilteo-shooting-suspect-was-jealous-over-ex-purchased-rifle-a-week-ago/

On October 22, 2014, Jaylen Fryberg^USPER, a 15-year-old high school student, sent a group text message to his friends to meet in the cafeteria of Marysville Pilchuck High School for lunch, then shot each one in the head with a Beretta .40 caliber handgun, killing four and injuring two others before killing himself.[xxiv] While the motive for killing was never fully determined, it became one of the ten deadliest school shootings in U.S. history.[xxv]



On May 30, 2012, Ian Stawicki^USPER opened fire at a small Seattle café, shooting several people, killing four and injuring another. He then fled the scene and hijacked a car, killing the woman occupying it. The spree finally ended nearly five hours later when confronted by police in West Seattle, he dropped to his knees and shot himself. The shooting occurred after he was asked to leave the cafe for acting belligerently. [xxvi, xxvii]

On June 22, 2011, Abu Khalid Abdul-Latif^USPER and Walli Mujahidh^USPER were arrested for planning to attack the Military Entrance Processing Station (MEPS) in Seattle with machine guns and grenades after previously planning, but discounting, an attack at Joint Base Lewis McChord (JBLM). According to FBI investigators, "Abdul-Latif said that 'jihad' in America should be a 'physical jihad,' and not just 'media jihad.'"[xxviii]

Bombings: A device fabricated in an improvised manner incorporating destructive, lethal, noxious, pyrotechnic or incendiary chemicals and designed to destroy, incapacitate, harass or distract. These devices are often placed *(Improvised Explosive Device (IED))* or worn (*Suicide-Vest Improvised Explosive Device (SVIED)).*[xxix] *Vehicle-Borne Improvised Explosive Devices (VBIED)* use explosives to weaponize vehicles and are aimed at killing a specific individual(s) and in attacks designed to achieve mass destruction to people and property, either set to detonate remotely or by some type of trigger.[xxx]

On April 9, 2015, Blake Heger^USPER was arrested after attempting to place two shrapnel-laden pipe bombs near a high foot-traffic area outside a hardware store in Puyallup, WA. Police were called after a concerned citizen saw him sharpening large knifes in the parking lot. He was found with two additional pipe-bombs, four large knives and a screwdriver that he had sharpened into a dagger. An explosives expert said the IEDs were "capable of hurling shrapnel up to 15 feet with deadly force."[xxxi, xxxii]

[xxiv] http://www.newsweek.com/2015/09/25/jaylen-ray-fryberg-marysville-pilchuck-high-school-shooting-372669.html
[xxv] https://www.theodysseyonline.com/ten-deadliest-school-shootings-history
[xxvi] http://abcnews.go.com/US/ian-stawicki-seattle-cafe-racer-shooter-kills-shoots-citywide/story?id=16463885
[xxvii] https://www.seattletimes.com/seattle-news/gunman-a-life-full-of-rage-a-shocking-final-act/
[xxviii] http://www.foxnews.com/us/2012/06/05/seattle-terror-suspect-wants-evidence-tossed58114/#ixzz28jz1MkOE
[xxix] http://www.smallarmssurvey.org/fileadmin/docs/D-Book-series/book-05-Conventional-Ammo/SAS-Conventional-Ammunition-in-Surplus-Book-16-Chapter-14.pdf
[xxx] http://terrorism.about.com/od/tacticsandweapons/g/CarBombing.htm
[xxxi] http://www.kiro7.com/news/man-arrested-after-two-bombs-discovered-outside-pi/28802706
[xxxii] http://komonews.com/news/local/police-dangerous-person-put-explosive-device-near-puyallup-store

On January 17, 2011, Kevin Harpham[USPER], an admitted white supremacist, placed a remote-controlled backpack improvised explosive device (IED), with rat-poison coated shrapnel, at a park bench near the marching route on the morning of the Martin Luther King Jr. Day Parade in Spokane, WA. Prosecutors said the device was "constructed with a clear, lethal purpose," and Harpham said it was intended to protest social concepts, such as unity and multiculturalism.[xxxiii] (see the 'CBRN Attack / Bomb' section below for more)

On November 26, 2010, Mohamed Osman Mohamud[USPER] was arrested and accused of plotting to bomb Pioneer Courthouse Square in Portland, OR during a Christmas tree-lighting ceremony. An estimated 10,000 people were in attendance during the attempt. Mohamud was charged with attempting to use a weapon of mass destruction, after he tried to detonate what he thought was a car bomb at the packed ceremony.[xxxiv]

Arson and Firebombing: Any willful or malicious firebombing, burning or attempt to burn with the intent to defraud, harm or kill others, or destroy property including a dwelling house, public building, motor vehicle or aircraft, personal property, etc.[xxxv]

On January 14, 2017, Isaac Wilson[USPER], a homeless man, intentionally set a fire that burned down half of the Islamic Center of Eastside in Bellevue, WA. He admitted setting the fire when police arrested him in the parking lot. Although his motive was determined to be unrelated to terrorism or hate crime, the use of arson elevates the event to targeted violence. Wilson also had previous incidents at the mosque and was convicted of fourth-degree assault and disorderly conduct for incidents at the Center in 2006.[xxxvi, xxxvii]

On August 25, 2017, Melvin Neifert[USPER] was arrested and charged with receiving incendiary explosive device materials—specifically, potassium nitrate and other materials to make a potassium nitrate-sugar bomb—that were to be used in connection with the 2016 May Day events. Federal authorities seized evidence and questioned Neifert on May 1, the same day anti-capitalist demonstrations took place in Seattle.[xxxviii, xxxix]

On May 1, 2016, Wil Floyd[USPER] threw an improvised incendiary explosive device (IIED) at a police officer during a May Day protest in Seattle, WA. The unlit device shattered at the feet of an officer, whose pants became engulfed in flames once a

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[xxxiii] http://www.spokesman.com/stories/2011/dec/20/mlk-parade-bomber-seeks-guilty-plea-withdrawal/

[xxxiv] http://topics.nytimes.com/top/reference/timestopics/people/m/mohamed_osman_mohamud/index.html

[xxxv] http://www2.fbi.gov/ucr/cius2009/offenses/property_crime/arson.html

[xxxvi] http://komonews.com/news/local/man-pleads-guilty-to-bellevue-mosque-arson

[xxxvii] http://www.seattleweekly.com/news/man-pleads-guilty-to-reckless-burning-of-bellevues-islamic-center-of-the-eastside/

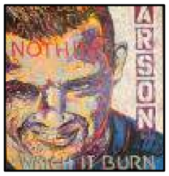
[xxxviii] https://www.seattletimes.com/seattle-news/crime/bail-decision-delayed-in-selah-explosives-case/

[xxxix] https://www.fbi.gov/contact-us/field-offices/seattle/news/press-releases/fbi-arrests-selah-man-for-receipt-of-an-explosive-device

nearby flash-bang grenade ignited the incendiary material. Floyd and other anarchist extremists injured four other officers with rocks, bricks and physical assault.[xl]

On September 4, 2016, a fire was intentionally set at the Planned Parenthood clinic in Pullman, WA. Authorities recovered a video from inside the clinic showing a flammable object had been thrown through the window. While no injuries were reported, and no suspects identified, there is a history of domestic terrorism against the Pullman clinic. The perpetrator is still at large.[xli, xlii, xliii]

On January 1, 2014, Musab Masmari[USPER] attempted to set fire to a gay nightclub on Capitol Hill in Seattle, WA by spilling gasoline down a set of stairs and lighting it, while 750 people packed the club's New Year's Eve event. According to investigative documents, Masmari told a friend that "homosexuals should be exterminated." In July 2014, he was sentenced to 10 years in federal prison for arson.[xliv, xlv, xlvi]

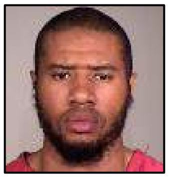


On February 30, 2013, a fire was intentionally set in an under-construction, 3-story townhouse in Seattle, WA, which was advertised as an "efficient green home." Local anarchists claimed responsibility for the fire that cost more than $30,000 in damages, stating the attack was aimed to "reject the status quo" and shed the "subjugated subjectivity" forced on them by the government.[xlvii, xlviii]

Murder / Assassination: The killing of a selected victim(s); typically for a political, religious or social-psychological effect.[xlix] Attacks against law enforcement and military personnel; abortion clinics and physicians; and the Lesbian, Gay, Bisexual, Transgender, Queer/Questioning (LGBTQ) community continue to be the most frequently targeted.

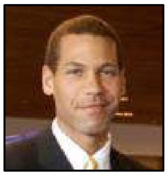
On October 27, 2014, Jaleel Abdul-Jabbaar[USPER] made repeated online threats to kill a former Ferguson, MO police officer, his family, and all other officers. The threats were made in regard to the fatal officer-involved shooting of unarmed Michael Brown[USPER] in August 2014. He stated, "We need to kill him and anything that has a badge on." Abdul-Jabbaar also used social media communications to attempt to acquire a firearm.[l, li]

[xl] https://www.seattletimes.com/seattle-news/crime/man-charged-with-tossing-molotov-cocktail-during-may-day-2016/
[xli] https://www.seattletimes.com/seattle-news/video-shows-object-thrown-in-planned-parenthood-arson-in-pullman/
[xlii] http://time.com/4023864/planned-parenthood-arson-washington/
[xliii] https://www.npr.org/sections/thetwo-way/2015/09/05/437829915/fire-at-washington-state-planned-parenthood-clinic-fire-deemed-arson
[xliv] https://www.fbi.gov/contact-us/field-offices/seattle/news/press-releases/man-who-set-fire-to-neighbours-nightclub-on-new-years-eve-pleads-guilty-to-federal-arson-charge
[xlv] http://www.kiro7.com/news/friend-said-gay-club-arson-suspect-may-be-planning/81846361
[xlvi] https://www.seattletimes.com/seattle-news/man-who-set-fire-in-capitol-hill-nightclub-sentenced-to-10-years/
[xlvii] http://www.kiro7.com/news/anarchists-claim-responsibility-judkins-park-arson/246221291
[xlviii] http://fireline.seattle.gov/2013/02/26/judkins-park-house-fire/
[xlix] http://www.terrorism-research.com/incidents/
[l] https://www.seattletimes.com/seattle-news/crime/kirkland-man-sentenced-for-threats-against-ferguson-cop/
[li] http://www.dailymail.co.uk/news/article-2937412/ISIS-sympathizer-pleads-guilty-making-Facebook-threats-against-life-ex-Ferguson-cop-Darren-Wilson-family.html



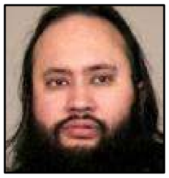
On July 18, 2014, Ali Muhammad Brown[USPER] was arrested after he killed four people in WA, including a gay couple, and a college student in NJ as part of a personal vengeance against the U.S. government for its actions in the Middle East. In 2004, he was arrested and prosecuted for his role in a bank fraud scheme to finance fighters traveling abroad, and had known links to a disrupted terror cell in Seattle, WA and Bly, OR in 1999.[lii, liii, liv]

On November 29, 2009, Maurice Clemmons[USPER] murdered four Lakewood, WA police officers in a local coffee shop, then fled. After a two-day manhunt, he attempted to shoot another police officer, but was shot and killed while he fumbled to pull the gun from his waistband. Clemmons had an extensive history of violence, incarceration and mental instability and was out on bail for rape of a child and assault.[lv, lvi]



On October 31, 2009, Christopher Monfort[USPER] set fire to police vehicles and murdered a police officer in Seattle, WA, culminating his politically-driven war against the Seattle Police Department. Monfort stopped his vehicle alongside the patrol car, opened fire on two officers, then fled the scene. He was seriously wounded after being shot during his arrest.[lvii] In January 2017, Monfort was found dead in his cell from an apparent suicide.[lviii]

CBRN Attack / Bomb: Weaponized chemical, biological, radiological and nuclear materials that are intentionally used in criminal acts with the intent to harm or kill others. Acts may include the deliberate dumping or release of hazardous materials, poisoning of one or more individuals, or contamination of food, livestock and crops.[lix]



On May 30, 2013, Matthew Buquet[USPER] mailed threatening letters containing active ricin toxin to a number of military bases and government officials, including a Washington-based U.S. District Court Judge. A post office in Spokane, WA ultimately intercepted the letters. Fortunately, the substance was not in a form that could be inhaled or readily ingested, and therefore no one was injured or at risk from handling the letters.[lx]

[lii] http://www.nj.com/essex/index.ssf/2016/01/accused_brendan_tevlin_killer_gets_lengthy_prison.html

[liii] http://www.dailymail.co.uk/news/article-2759901/Revealed-terrifying-one-man-jihad-U-S-soil-Extremist-executed-four-revenge-American-attacks-Middle-East-carried-bank-fraud-Cause.html

[liv] http://www.foxnews.com/us/2014/11/04/murder-suspect-on-personal-jihad-may-have-been-groomed-in-seattle-barber-shop.html

[lv] http://seattletimes.com/flatpages/specialreports/lakewoodslayings.html

[lvi] http://www.historylink.org/File/9677

[lvii] https://www.seattletimes.com/seattle-news/crime/monfort-sentenced-to-life-in-prison-for-killing-seattle-police-officer/

[lviii] https://www.seattletimes.com/seattle-news/crime/christopher-monfort-killer-of-seattle-police-officer-dies-in-prison/

[lix] http://www.publicsafety.gc.ca/pol/em/cbrnstr-eng.aspx

[lx] http://www.cnn.com/2013/05/22/justice/washington-ricin-letters/index.html

According to the FBI, Kevin Harpham's backpack bomb was a viable device that could have sprayed marchers and parade patrons with shrapnel and caused multiple casualties. The backpack he used had been cut to allow the insertion of a wooden-framed, 6-inch steel pipe, loaded with 128 quarter ounce weights that were coated with rat poison to act as an anti-clotting agent.[lxi]

Kidnappings and Hostage-Takings: The overt seizure of a facility or location and the taking of hostages; used to establish a bargaining position and to elicit publicity; for the purpose of gaining money, release of jailed comrades, and publicity for an extended period.[lxii]

There are no recent examples of kidnappings or hostage-takings in Washington State. However, in July 2006, Naveed Haq^{USPER} attacked the Jewish Federation in Seattle, WA. He gained access to the building by holding a 13-year-old girl hostage before he began a shooting spree inside the facility. He shot six, one fatally. On January 14, 2010, he was sentenced to life plus 120 years in prison without the possibility of parole.[lxiii, lxiv]

Hijacking and Skyjacking: The forceful seizure of an aircraft, surface vehicle, vessel, its passengers, and/or its cargo; often creates a mobile, hostage barricade situation.[lxv]

While there have been no hijacking or skyjacking incidents within the last 10 years, on July 11, 1980, 17-year-old Glenn Kurt Tripp of Arlington, WA, attempted to hijack Flight #608 at Seattle-Tacoma International Airport. He demanded $600,000, two parachutes and the assassination of his boss. On January 21, 1983, Tripp attempted to hijack another plane while it was in the air and requested the plane fly him to Afghanistan. The pilots landed in Portland, OR where he was shot and killed by FBI agents.[lxvi, lxvii]

In 2004, an Al Qai'da member told authorities that the original 9/11 attack plan called for terrorists to seize 10 planes and attack targets on both coasts, including a "black-glass skyscraper in Seattle." This is referring to the Columbia Center (formerly, the Bank of America Tower), a 76-story building in downtown Seattle, which was among many skyscrapers nationwide that were evacuated shortly after the 9/11 attacks.[lxviii, lxix]

Cyber Attack: A deliberate and criminal exploitation, disruption or destruction of information/data, computer systems, computer programs, technology-dependent enterprises and

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[lxi] http://www.spokesman.com/stories/2011/dec/20/mlk-parade-bomber-seeks-guilty-plea-withdrawal/
[lxii] http://www.terrorism-research.com/incidents/
[lxiii] http://www.nbcnews.com/id/14082298/ns/us_news-crime_and_courts/t/police-seattle-shooting-suspect-ambushed-teen/#.WpsHLrenFaQ
[lxiv] https://www.seattletimes.com/seattle-news/haq-apologizes-receives-life-sentence-for-jewish-federation-shooting/
[lxv] http://www.terrorism-research.com/incidents/
[lxvi] http://www.check-six.com/Crash_Sites/NWA305-DBCooper.htm
[lxvii] https://www.upi.com/Archives/1983/01/21/Attorney-Hijacker-couldnt-hurt-anyone/5733411973200/
[lxviii] http://www.spokesman.com/stories/2004/jun/17/seattle-high-rise-once-9-11-target/
[lxix] https://blog.nationalgeographic.org/2011/09/07/the-original-plans-for-911/

networks through the use of malicious code to alter computer code, logic or data; aka Computer Network Attack (CNA).[lxx]

In October 2012, actors claiming affiliation with the hacktivist group Anonymous threatened to launch "Operation Grand Jury Resisters" in response to the treatment of individuals implicated in federal crimes that occurred during May Day activities in Seattle. Online personas specifically cited the City of Seattle's public website, the FBI and the district's U.S. Attorney's Office as targets for cyberattacks.[lxxi, lxxii]

Maritime Attack: The undertaking of criminal acts and activities within the maritime environment, using or against vessels or fixed platforms at sea or in port, or against any of passengers or personnel, against coastal facilities or settlements, including tourist resorts, port areas and port towns or cities.[lxxiii]

While there have been no attacks against Washington's maritime sector, a successful attack would have a significant economic and psychological impact. Washington has the fourth largest seaport alliance[lxxiv] in the U.S. and is home to the nation's largest ferry fleet, which services approximately 25.5 million riders per year.[lxxv] It is also home to the largest west coast cruise ship port, which annually hosts more than 200 cruise ships, holding more than 1 million passengers, and generates up to $500 million for the local economy, according to the Port of Seattle.[lxxvi][lxxvii]

Other Explosives or Weapons: The calculated use of improvised explosives or other weapon types in order to attain goals that are political or religious or ideological in nature. This category includes other weapons and tactics such as the use of vehicles, knives or other bladed weapons, drones, artfully concealed improvised explosive devices, or terror attack using a weapon type not already covered.[lxxviii]

On September 8, 2011, Michael McCright[USPER] was arrested and charged with second-degree assault for a July 2011 incident where he intentionally swerved his vehicle at a government-plated vehicle occupied by two U.S. Marines in Seattle. Known on the Internet as "Mikhail Jihad," McCright had ties to Abu Khalid Abdul-Latif, a man convicted of plotting to kill federal employees and military recruits in Seattle, WA.[lxxix, lxxx]

[lxx] http://www.techopedia.com/definition/24748/cyberattack, http://www.crime-research.org/articles/Cyber_Terrorism_new_kind_Terrorism/

[lxxi] https://anoninsiders.cyberguerrilla.org/opgjresisters-971/index.html

[lxxii] https://nopoliticalrepression.wordpress.com/2012/07/26/hello-world/

[lxxiii] http://www.maritimeterrorism.com/definitions/

[lxxiv] The Northwest Seaport Alliance, comprised of the seaports of Seattle and Tacoma, is the fourth largest gateway in North America by volume, and the fourth largest port by export value. https://www.nwseaportalliance.com

[lxxv] http://www.wsdot.wa.gov/ferries/traffic_stats/annualpdf/2017.pdf

[lxxvi] https://www.portseattle.org/sites/default/files/2018-05/POS_1805_CruiseEnvirnoment.pdf

[lxxvii] https://www.portseattle.org/Cruise/Documents/2018_cruise_fact_sheet.pdf

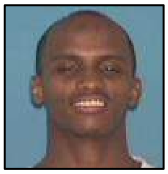
[lxxviii] http://www.terrorism-research.com/incidents/

[lxxix] https://www.seattletimes.com/seattle-news/felon-admits-he-tried-to-run-marines-off-i-5/

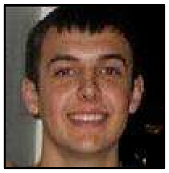
[lxxx] http://www.seattlepi.com/local/article/Secret-evidence-at-issue-in-South-Seattle-3359677.php#page-1

Support to Terrorism: Anyone who provides material support or resources or conceals or disguises the nature, location, source or ownership of material support or resources, knowing or intending that they are to be used in preparation for, or in carrying out, an act of terrorism or violent extremism.[lxxxi]

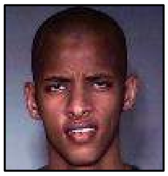
On March 31, 2017, and Hinda Osman Dhirane[USPER] of Ken, WA, and Muna Osman Jama[USPER] were sentenced to 12 years and 11 years respectively, after being found guilty of conspiracy to provide material support to al-Shabaab. The two reportedly organized an all-female fundraising group called the "Group of Fifteen," which provided monthly payments to Al-Shabaab; facilitating and tracking money sent through conduits in Kenya and Somalia.[lxxxii]



On October 27, 2012, Abdisalan Hussein Ali[USPER], a 22-year old born in Somalia but raised in Seattle and Minnesota, was the third American killed as an Al-Shabaab suicide bomber in Mogadishu. Ali was reportedly one of two bombers in an attack that killed "scores of African Union peacekeepers." He arrived in Seattle in 2000 and moved to Minneapolis before being recruited into al-Shabaab and travelling to Somalia in 2008.[lxxxiii]



On May 11, 2011, Joseph Brice[USPER] of Clarkston, WA, was arrested for assembling, practicing and detonating explosive devices after an incident that occurred on April 18, 2010, when an explosive device he made prematurely ignited, causing him significant injuries. He had a YouTube[USBUS] channel called "Strength of Allah," where he posted the videos in an attempt to support terrorism.[lxxxiv, lxxxv, lxxxvi]



In April 2009, Abdifatah Yusuf Isse[USPER] , a graduate of Roosevelt High School in Seattle, pled guilty to training with and providing material support to al-Shabaab, beginning in December 2007. Isse also admittedly had contact with Shirwa Ahmed, the first known American Al-Shabaab suicide bomber, while he was being trained in Somalia. Isse served time in prison for providing material support to an FTO, and will remain under supervised release for 20 years.[lxxxvii, lxxxviii]

Probability of Future Events

[lxxxi] http://www.fas.org/sgp/crs/natsec/R41333.pdf

[lxxxii] https://www.justice.gov/opa/pr/two-women-sentenced-providing-material-support-terrorists

[lxxxiii] http://www.nytimes.com/2011/10/31/world/africa/shabab-identify-american-as-bomber-in-somalia-attack.html?_r=0

[lxxxiv] https://www.seattletimes.com/seattle-news/man-indicted-for-making-bomb-in-clarkston/

[lxxxv] http://www.spokesman.com/stories/2013/jun/12/bomb-maker-sentenced/

[lxxxvi] https://archives.fbi.gov/archives/seattle/press-releases/2013/clarkston-man-sentenced-to-federal-prison-for-attempting-to-provide-material-support-to-terrorists

[lxxxvii] https://www.mprnews.org/story/2015/02/04/isse-released

[lxxxviii] http://minnesota.cbslocal.com/2012/10/08/minn-trial-reveals-details-of-life-with-al-shabab/

Due to the wide variety of terrorism and violent extremism types, the likelihood of any act of terrorism or violent extremism taking place in Washington State is estimated to occur annually. With terrorist and violent extremist attacks and plots becoming more consistent, Washington State has encountered more than 40 attempted and successful attacks in the past decade, averaging four per year.

As recently demonstrated in attacks all around the world, crowded pubic venues, transportation hubs, military facilities and law enforcement continue to be some of the most frequent targets of violent extremist attacks. And small-scale tactics continue to wreak havoc in places or areas where people once felt safe. Key physical and environmental factors are often used to determine targets by calculating the probability of an attack's success—including, but not limited to, the potential number of victims, ease of ingress and egress, levels of security and target status. Within these soft-target environments, small-scale tactics afford violent extremists the opportunity to have a negative economic impact, cause mass casualties and provide an iconic victory.

Furthermore, violent extremist propaganda continues to urge lone actors in the West to attack soft targets using small arms, knives, concealable IEDs and other improvised weapons because they are simple and effective. In January 2015, former ISIS spokesman Mohammad al-Adnani said to use "whatever means available… an explosive device, bullet, knife, car, rock, or even a boot or a fist."[lxxxix]

- The "Just Terror Tactics" section in ISIS' *Rumiyah* magazine has highlighted knife, vehicle and fire bombing attacks, along with detailed suggestions for each tactic. Since then, there have been numerous successful and failed attempts to implement these tactics.[xc, xci]

- Al-Qa'ida in the Arabian Peninsula's *Inspire* magazine provides tactical guidance and step-by-step instructions for various weapons and tactics within its "Open Source Jihad" section, which included instructions for creating IEDs with household items; building pressure-cooker bombs, VBIEDs, and package or parcel bombs; and using vehicles as weapons.[xcii]

- In August 2016, ISIS released a propaganda video urging lone actors to commit jihad against the West by using household objects—including "baseball bats, power drills, screwdrivers or hypodermic needles" —as a way to "avert attention from the attacker, increasing the potential for a surprise attack against unsuspecting victims," according to a news media outlet.[xciii, xciv]

- In April 2013, a video from 2011 resurfaced featuring al-Qa'ida spokesman Adam Gadahn^{USPER}, who emphasized shooting attacks, which he said, "require less specialized

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[lxxxix] https://www.voanews.com/a/new-low-tech-terror-attacks-simple-deadly/3423383.html

[xc] http://www.independent.co.uk/news/world/middle-east/isis-ramadan-2017-all-out-war-west-new-terror-attacks-manchester-suicide-bombing-islamic-state-a7758121.html

[xci] http://www.nydailynews.com/news/national/manhattan-terror-truck-attack-isis-magazine-instructions-article-1.3604328

[xcii] https://www.ict.org.il/UserFiles/ ict-lone-wolf-osint-jihad-wiskind.pdf

[xciii] https://pjmedia.com/homeland-security/2016/08/21/calling-for-another-nice-style-attack-isis-suggests-jihadists-try-baseball-bat-power-screwdriver/

[xciv] www.newsy.com/stories/new-isis-video-tells-terrorist-to-use-everyday-items/

training than bombings or other tactics and may have a better chance of succeeding." Gadahn went on to discuss how easy it is to buy guns in the U.S. and urged fellow radicals to do so.[xcv]

Jurisdictions at Risk

Terrorists and violent extremists continue to demonstrate their desire to commit acts of terrorism in highly populated or high-profile areas, mainly to garner increased media attention and increase the psychosocial impacts. However, critical infrastructure sites and public events in non-densely populated regions have been the targets of foiled terror plots in Washington State, as well. The map below displays the population densities of counties within Washington. Highly populated counties tend to have a heavier infrastructure base to support a large population and, therefore, typically have more potential targets for terrorists and violent extremists seeking to inflict harm on these types of systems. This is not to say that these are the only target-rich environments. Intelligence reporting indicates terrorists' interests in targeting infrastructure such as dams, food supplies or cyber infrastructures, which can be located in sparsely-populated areas or have assets which are not centralized to one specific locale.

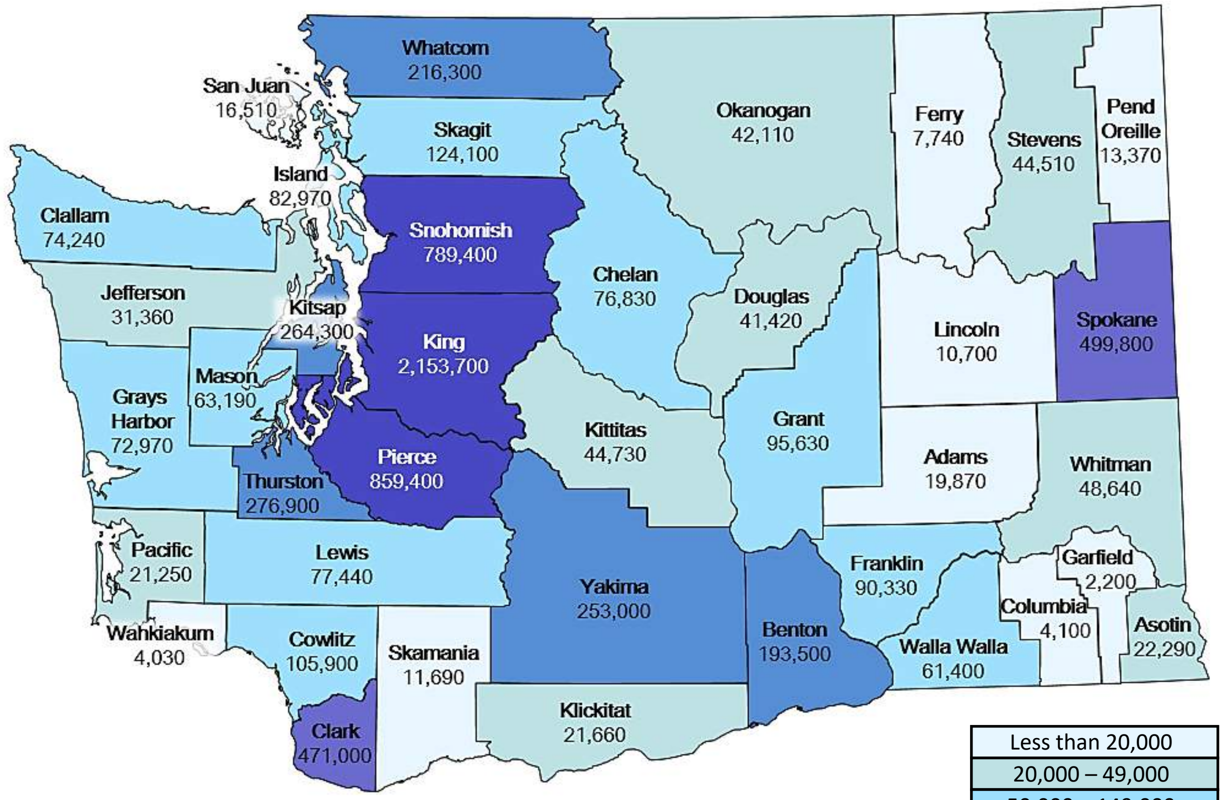

FIGURE 1: MAP OF WASHINGTON POPULATION DENSITIES BY COUNTY: DENSITIES ARE BASED ON APRIL 2017 POPULATION ESTIMATES FROM THE WASHINGTON STATE OFFICE OF FINANCIAL MANAGEMENT.[xcvi] ESTIMATED STATE POPULATION TOTAL = 7,310,300.

[xcv] http://www.cnn.com/2013/04/11/politics/al-qaeda-video/index.html

[xcvi] https://www.ofm.wa.gov/sites/default/files/public/legacy/pop/april1/ofm_april1_population_final.pdf

Communities vulnerable to terrorist incidents are those that have high visibility or are internationally known (i.e., Seattle, Bellevue, Olympia, Spokane), and those communities containing highly visible targets. The Department of Homeland Security has identified 16 critical infrastructure and key resource (CIKR) sectors which covers the gamut of facilities, sites, routes and systems which are most vulnerable to acts of violence, intrusion, or destruction. Additionally, special events or sites attracting large gatherings tend to be the most lucrative targets due to the high volumes of potential victims, and become even more appealing during visits by high profile personalities and dignitaries. Examples of high impact targets within the 16 CIKR sectors, in no particular order, include:

- **Commercial buildings**: stadiums, concert venues, convention centers, theatres, parks, shopping malls, casinos, etc.
- **Cyber/information technology**: system networks, power grids, communication industry, etc.
- **Special events**: parades, festivals, concerts, sporting events, other planned celebrations, etc.
- **Government**: courthouses, schools, universities, etc.
- **Law enforcement/emergency services**: first responders and all law enforcement facilities, equipment, personnel, etc.
- **Defense**: military bases, facilities, airfields, equipment, personnel, national laboratories, etc.
- **Transportation**: airports, bridges, ferries, interstate highways, passenger rail, tunnels, seaports, hazardous materials pipelines, etc.
- **Dams, water reservoirs and the power distribution network**: operating systems, facilities, etc.
- **Financial institutions/banks**
- **Food and Agriculture:** food products at point-of-sale, distribution and storage, etc.
- **Healthcare and Public Health:** hospitals, public health facilities, etc.
- **Historical landmarks, monuments, museums and other iconic sites**

Current Overwatch

The FBI is the lead agency in the U.S. for all matters concerning terrorism and violent extremism. Therefore, the current mitigation plan for such events in Washington State mirrors that of the FBI's national-level procedures and guidelines. While mostly predetermined, specific outreach, coordination and resources in response to a terror incident will be customized for the incident at that time. Currently, the Seattle Field Office of the FBI has various resident agencies and tasks forces operating to address terrorism matters, including:

- **Puget Sound Joint Terrorism Task Force (PS-JTTF)**: based in Seattle, WA (covers Regions 1, 2, 6)
- **Inland Joint Terrorism Task Force (IN-JTTF)**: based in Liberty Lake, WA (covers Regions 7, 8, 9)

- **South Sound Joint Terrorism Task Force (SS-JTTF)**: based in Tacoma, WA (covers Regions 3, 4, 5)

"Protecting the U.S. from terrorist attacks is the FBI's number one priority. The Bureau employs a variety of disciplines and works closely with a range of partners to neutralize terrorist cells and operatives here in the U.S., help dismantle extremist networks worldwide, and cut off financing and other forms of support provided to FTOs by terrorist sympathizers. The JTTFs bring federal, state, and local agencies together, to leverage the skills, authorities, and accesses to prevent and disrupt terrorist attacks across the country. In addition to state, local, and tribal law enforcement agencies, key partners with the FBI's counterterrorism efforts in the Northwest also include officers, investigators, and analysts from the Washington State Fusion Center and a myriad of other intelligence and public/private sector agencies. The JTTFs also build relationships between the community and law enforcement on the front line, which is particularly important to combatting terrorism."[xcvii]

Assessment

Acts of terrorism and violent extremism are some of the most challenging of all hazards to face. While hurricanes, earthquakes and other natural disasters can be scientifically forecasted, tracked and somewhat safeguarded against, acts of terrorism are far less predictable. Furthermore, identifying what measures to take once a threat is detected, or an attack is in progress, is more of an art than science. Appropriate response strategies must be malleable, as they are dependent upon the specific combination of—among dozens of other factors—the time of attack, specific location, weapon(s) used, tactics employed, target(s) effected, number of perpetrators, number of potential victims, barriers, and response resources available at that time. Dozens of factors equate to thousands of possible combinations, and a seemingly infinite number of attack scenarios that could play out anywhere within the State.

Take for example, the complex coordinated attack in Paris in 2015. Eight operators carried out this attack by conducting coordinated hostage-takings, mass shootings and bombings spanning across six different locations within the city. The targets covered a wide range of critical infrastructure sectors by attacking restaurants, an office building, a concert venue, a sports stadium and the local populace. A total of 130 people were killed, 352 were wounded and damage to the city was estimated to be [equivalent to] more than $2 billion USD.[xcviii, xcix, c] However, the entire operation likely cost the terror cell less than $10,000 which included weapons, explosives, housing and transportation.[ci] Conversely, consider the Las Vegas shooting in 2017, where Stephen Paddock[USPER] carried out the most deadly mass shooting in recent history from his hotel room above a crowd of concert goers. This attack was conducted by one man, with his own legally-purchased firearms, after months (or years) of planning. He was able to singlehandedly kill 58 people and wound 422 others.[cii] Property damage was slight in comparison, but the psychosocial effects felt by U.S. citizens were likely comparable to that of the Paris attacks.

[xcvii] https://www.fbi.gov/investigate/terrorism

[xcviii] https://www.cnn.com/2015/12/08/europe/2015-paris-terror-attacks-fast-facts/index.html

[xcix] http://www.ibtimes.com/how-many-people-died-paris-shooting-update-mass-attacks-french-capital-2184689

[c] https://qz.com/559902/the-paris-attacks-will-cost-the-french-economy-more-than-2-billion/

[ci] https://www.nbcnews.com/storyline/paris-terror-attacks/terror-shoestring-paris-attacks-likely-cost-10-000-or-less-n465711

[cii] https://lasvegassun.com/news/2018/jan/19/sheriff-to-provide-update-about-strip-mass-shootin/

The differences in those two examples alone illustrate why man-made threats, unless detected and thwarted early, are challenging for response strategies. While homeland security efforts continue to improve, the undying persistence of threat actors and the growing use of terror tactics necessitate the need for vigorous countermeasures. Expanding or augmenting the identification of potential threats, and implementing security measures aimed to deny violent extremists opportunities to cause harm, will be vital in this endeavor. Most importantly, consistent multi-agency collaboration, collective mitigation planning, training exercises and robust information sharing efforts continue to be ‘best practices’ for thwarting or mitigating the impacts of terrorism and violent extremism in Washington State.

Tsunami Risk Summary

Washington State Risk Index for Tsunamis (WaSRI-TS)	**MEDIUM-LOW**	
LIKELIHOOD	MEDIUM	There is a 10-20% chance of a Cascadia Subduction Zone earthquake in the next 50 years, according to the Pacific Northwest Seismic Network.
HAZARD AREA	LOW	Only low-lying coastal areas are at direct risk from tsunamis resulting in a "Low" exposure determination for the state as a whole.
POPULATION	LOW	This "Low" ranking reflects that less than 1% of the State population reside in coastal shoreline counties exposed to tsunamis. However, this 1% may be ranked as **"high"** being severely impacted with much loss of life for stranded coastal populations.
VULNERABLE POPULATION	MEDIUM	32% of population in tsunami inundation zones is also ranked medium or higher on social vulnerability.
BUILT ENVIRONMENT	LOW	Less than 2% of the general building stock of the State is located in areas exposed to tsunamis. These limited impacted areas will suffer extensive property and structural loss.
CRITICAL INFRASTRUCTURE	LOW	Although less than 5% of the facilities are located in coastal shoreline counties are in tsunami inundation zones transportation corridors within impacted areas may have very limited functionality following a tsunami
STATE FACILITIES	LOW	2% of state owned facilities located in coastal shoreline counties are in tsunami inundation zones. 5% of the State Leased facilities located in coastal shoreline counties are in tsunami inundation zones.
FIRST RESPONDERS	LOW	4% of the fire stations located in coastal shoreline counties are in tsunami inundation zones. 4% of the law enforcement located in coastal shoreline counties are in tsunami inundation zones. 2% of the EMS facilities located in coastal shoreline counties are in tsunami inundation zones.
ECONOMIC CONSEQUENCES	MEDIUM	Counties ranked high or medium-high on WaSRI-L account for less than 1% of real State GDP. However, cumulative long-term impacts on coastal businesses, marine industry and other associated activities are expected to be significant.
ENVIRONMENTAL IMPACTS	MEDIUM-HIGH	Tsunamis can lead to major changes in the coastal environment. Some ecological resources may recover in a few years, but the impact on threatened marine specifies may be catastrophic. Existing coastal lands may disappear.

Tsunami Hazard Profile

Hazard Description

Tsunamis means *harbor wave* in Japanese, referring to the characteristic of highest wave heights in the bays and harbors. Tsunamis are a series of extremely long waves caused by a large and sudden displacement of water. This is usually the result of an earthquake or volcanic eruption underwater, but can also be caused by landslides flowing into bays or occurring underwater. Tsunamis can occur in oceans, seas, lakes and rivers, although those occurring in closed bodies of water are often referred to as seiches. The most destructive tsunamis often occur in the ocean and are caused by earthquakes; 59 percent of the world's tsunamis occur in the Pacific Ocean Basin. Tsunamis pose a threat to people and property located along Washington State's coastline, Strait of Juan de Fuca, Puget Sound, large lakes and rivers.

In the ocean, typical waves have a wavelength (measures from crest to crest) of about 330 feet. In comparison, tsunami waves have very long wavelengths, typically spanning tens or hundreds of miles. With waves that can move at the speed of a jetliner in open ocean, up to 600 miles per hour, tsunamis can travel across the entire ocean basin. Unlike hurricanes, they can occur in any season of the year and at any time of the day. Tsunamis tend to only be a threat when they approach land and impact human settlements, tending to cause the most severe damage and casualties near their source. Children and the elderly are among the most vulnerable populations.

Tsunamis are walls of moving water that go all the way down to the ocean or lake floor. The entire water column moves within it. This is different than typical waves that tend to move across the surface and leave the depths undisturbed. Although warning signage uses the image of a cresting wave, tsunamis with breaking waves are less common than a wall of moving water. They have been mistakenly referred to as tidal waves but are not tide related. Out in the ocean, a tsunami wave may only register as a few inches or feet rise in the surface. But as these waves approach shorelines and shallower depths, they grow in size. The underwater topography, configuration of the shoreline, infrastructure and debris work to shape the tsunami waves and impacts.

Powerful tsunamis can travel several miles over low lying coastal land. The wave causes destruction as it travels across land and as it recedes back into the ocean dragging debris with it. Multiple tsunami waves can strike the coastline for hours to days following an earthquake event. The 1964 Alaska earthquake struck Crescent City, CA in a series of four waves. The first wave was 9 feet above tide; the second was 6 feet above tide; the third wave was 11 feet above tide and the last wave was 16 feet above tide. The last two waves killed 11 people. In Washington state's Willapa Bay, the biggest wave arrived 12 hours after the first wave struck.

This moving wall of water can cause tremendous damage. The strength of the tsunami is determined by the magnitude of the triggering event and the proximity to shore. The 2011 Tohoku 9.0M earthquake was 43 miles off the coast of Japan. The resulting tsunami caused enormous loss of life and property including the failure of the Fukushima Daiichi Nuclear Power Facility. In the city of Miyako, the waves were 133 feet high and there were places in the Sendai area where the waves traveled up to 6 miles inland. Huge concrete barriers built to protect cities and towns against tsunamis were over-topped, in part, due to ground subsiding 6 to 9 feet due to the earthquake. In all, Japan suffered inundation over 217 square miles of dry land. At this time, this is the costliest natural disaster in world history.

Earthquake-Generated Tsunamis

Most tsunamis are generated as a result of underwater normal or reverse faulting earthquakes associated with sudden rise and fall of the sea-floor displacing a large volume of water. The height of a tsunami wave depends on the magnitude of the earthquake, area of the rupture zone, rate and volume displaced, nature of ocean floor motion and depth of water above the rupture.

Just as earthquakes cannot be predicted, neither can the tsunamis they produce. Based on past history, scientists can provide general probabilities of the likelihood of an earthquake in a given span of time. Once a tsunami has occurred, sensors in the ocean can provide warning and potential impacts can be modeled. Tide gages along coastlines also provide critical data. The time available for evacuation will depend how close the triggering source is to land and when or if the public receives a warning. Tsunamis that occur in local water bodies due to landslides may provide almost no warning given the short travel distances.

There can be some natural warning signs prior to a tsunami. One sign is water receding rapidly from the shore and revealing areas usually covered by water. Another sign is a roaring sound like an approaching freight train. Severe ground shaking is yet another indicator. Some tsunamis do not cause receding water and earthquakes occurring far out in the ocean may not be felt.

Maritime Concerns

Port and harbor facilities along Washington’s coast are especially vulnerable to near source tsunamis although distant tsunamis may also pose a threat. For example, in California following earthquakes in 2006 (Kuril Islands), 2010 (Chile), and 2011 (Japan), harbors sustained over $100M in damages (California Geological Survey, 2018). Wave velocity, debris fields, oil spills, and the shifting of the sea floor can impact shipping lanes and the fishing industry. Even small tsunami waves can cause significant damage to marina’s, harbors and ports. Since Washington state has such an extensive network of waterways including the Strait of Juan de Fuca, the Puget Sound, this hazard is of special concern. According to the California Tsunami program, however, 80 to 90 percent of the damages caused by a distant-source tsunami could be prevented or reduced by implementing key tsunami mitigation actions.

Tsunami Location, Extent, and Magnitude

Washington's coastline facing the Pacific Ocean has two different tsunami threats. Tsunamis generated as far away as Alaska and Japan can cross the ocean and impact the Washington's coastline (distant sources). There are four types of tsunamis that threat Washington communities. Each of these affect different parts of the state as summarized in the table below.

Types of tsunamis and who they affect (Source: DNR)

Type of Tsunami	Description	Area of greatest impact	Time to evacuate
Distant	A tsunami is created by a distant earthquake or landslide and travels across the ocean	Pacific coastal communities	Hours
Cascadia subduction zone	Tsunami created by large M8–9 earthquake off the Washington, Oregon, or British Columbia coasts	Pacific coastal communities	Tens of minutes
Local earthquake (for example, the Seattle or Tacoma faults)	Tsunami created in large body of water from an earthquake on local faults	Communities close to the body of water	Minutes to tens of minutes
Landslide-caused tsunami	Large landslide occurs underwater or slides from land into water	Depends on where the landslide occurs	Minutes to tens of minutes

Washington Geological Survey produces maps of tsunami inundation and evacuation brochures to help emergency managers and people plan for tsunami events. Specific scenarios of earthquakes are utilized to model tsunami inundation areas. Research about the occurrence of great earthquakes off the Washington, Oregon and northern California coastlines and resulting tsunamis indicates that locally generated (nearby) tsunamis that will leave little time for response (Atwater, 1992; Atwater and others, 1995). Past studies have found geologic evidence of tsunami deposits attributed to the Cascadia subduction zone (CSZ) in at least 59 localities from northern California to southern Vancouver Island (Peters and others, 2003). Inferred tsunami deposits have been identified inland as far east as Discovery Bay, just west of Port Townsend (Williams and others, 2002), and on the west shore of Whidbey Island (Williams and Hutchison, 2000). Washington Department of Natural Resources, Division of Geology and Earth Resources, in cooperation with the Washington Emergency Management Division has create a series of tsunami inundation maps based on multiple likely scenarios.

Tsunami hazard map for the Anacortes-Whidbey Island Area below shows modeled tsunami inundation from a Cascadia Subduction Zone earthquake (Timothy et. al. 2005). The earthquake scenario adopted for this study was developed by Priest and others (1997) and designated Scenario 1A (Myers and others, 1999). This scenario provides the best fit scenario for the A.D. 1700 event.

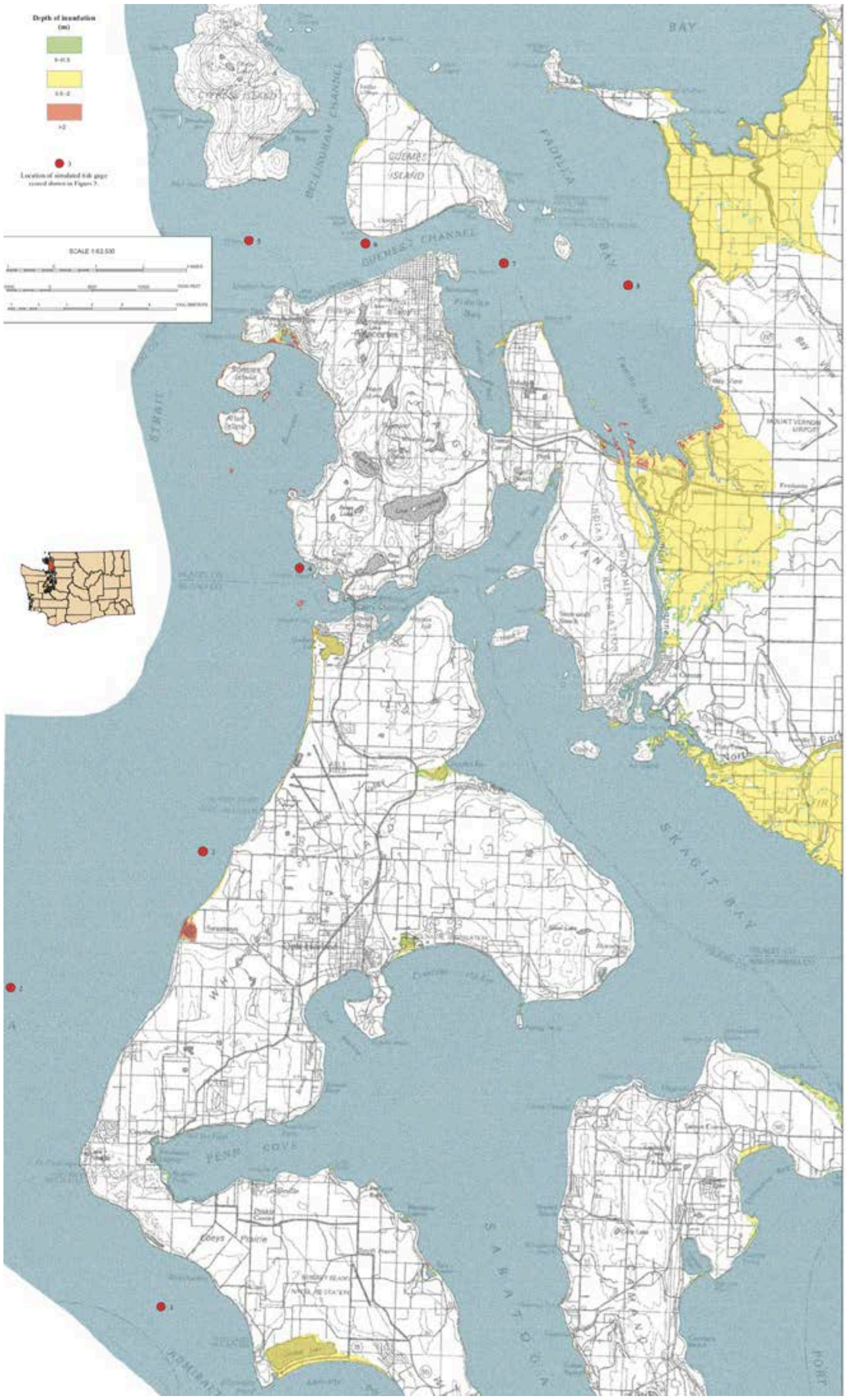

FIGURE TS 1: TSUNAMI HAZARD – ANACORTES-WHIDBEY ISLAND AREA (WALSH ET AL. 2005)

The same earthquake scenario was utilized to model inundation in Bellingham (Walsh et. al. 2004), and the Southern Washington coast (Walsh et. al. 2000).

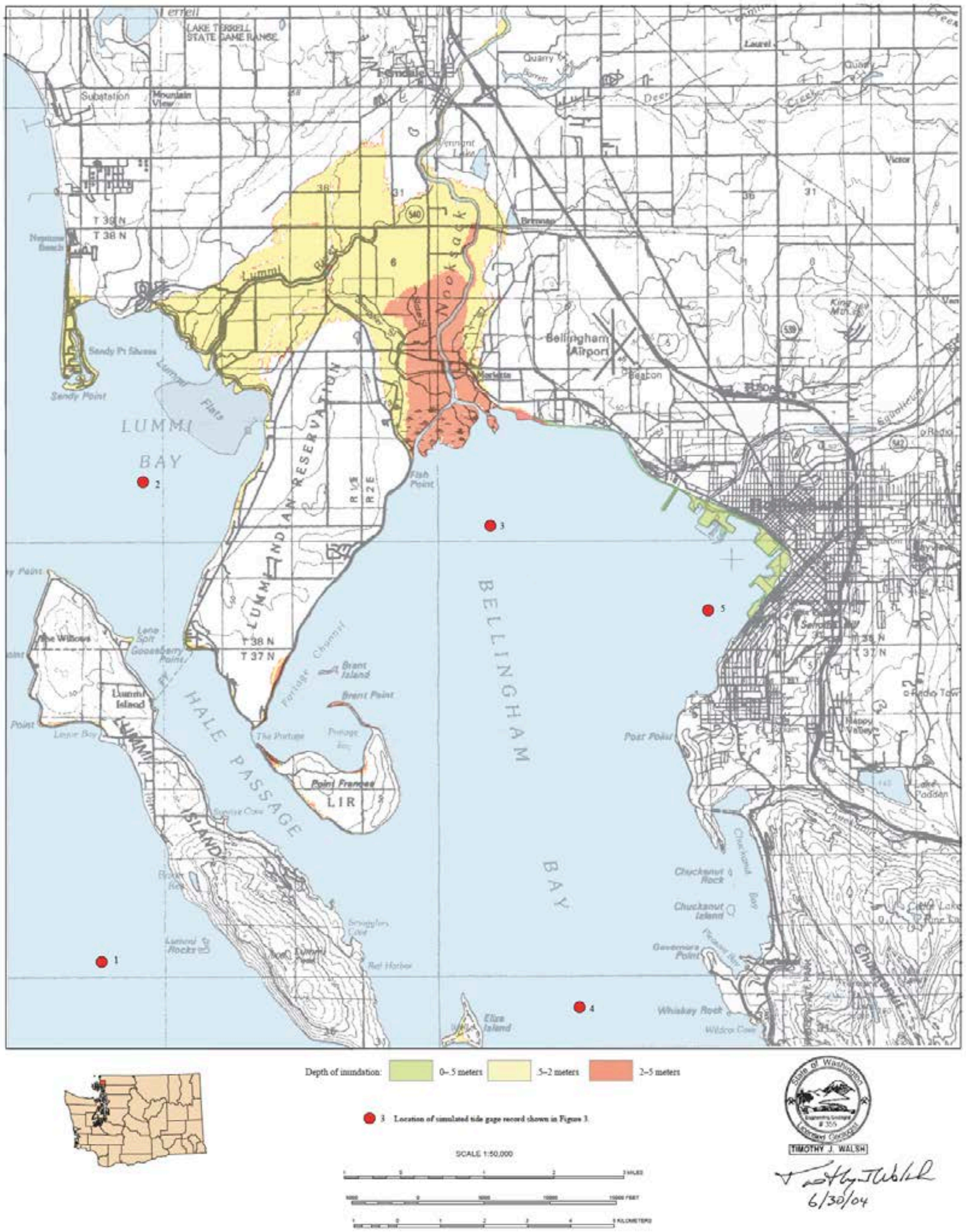

FIGURE TS 2: TSUNAMI HAZARD – BELLINGHAM AREA (WALSH ET AL. 2004)

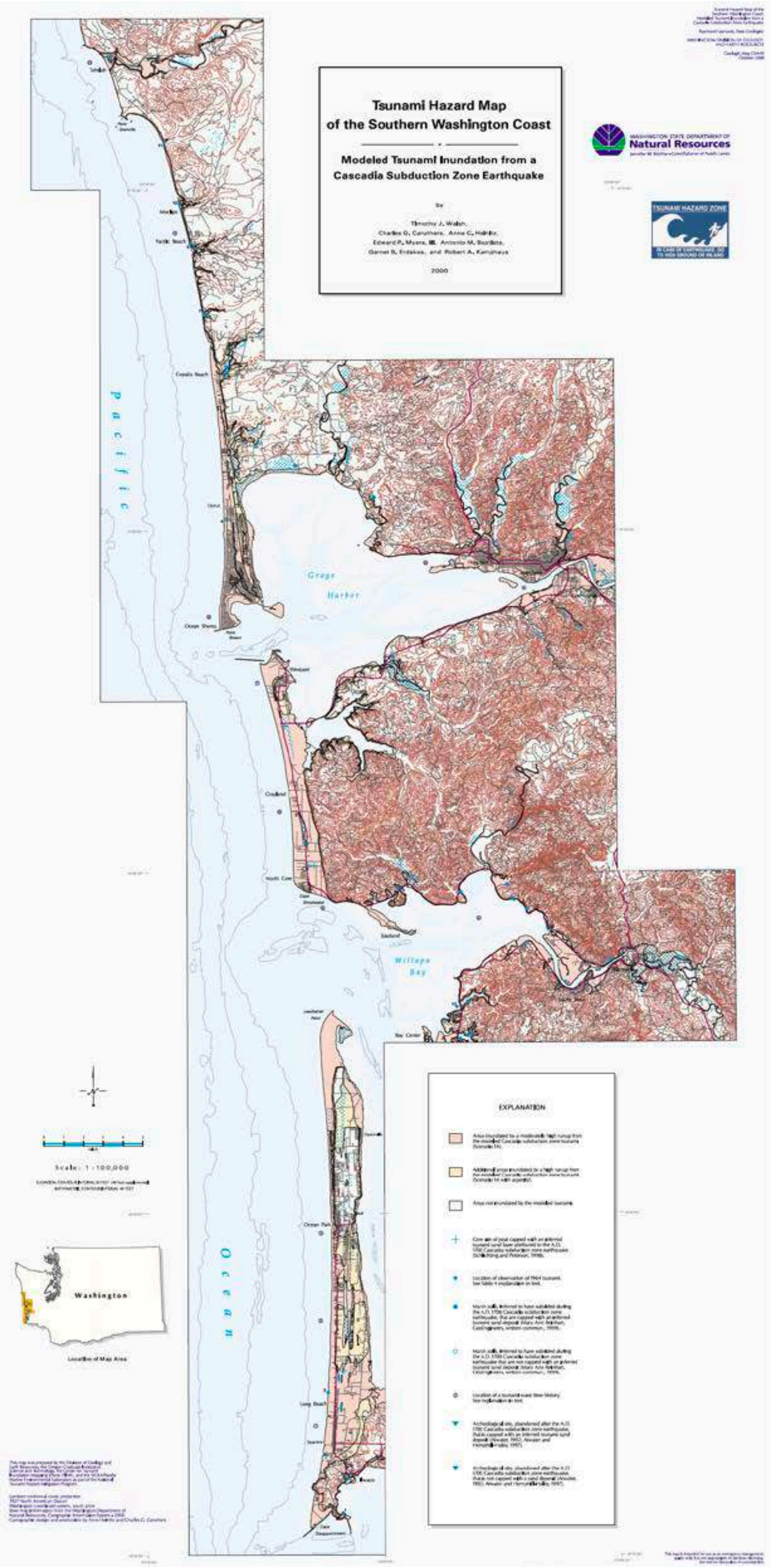

FIGURE TS 3: TSUNAMI HAZARD – SOUTHERN WASHINGTON COAST (WALSH ET AL. 2009)

For Everett, the Method of Splitting Tsunami (MOST) model by Titov and Synolakis (1998) was used to simulate the generation, propagation, and inundation. This MOST model study, uses two deformation models for the Seattle fault: Scenario A simulates the AD 900 to 930 event as a credible worst-case scenario of magnitude Mw 7.3. Scenario B simulates a less severe, but more likely Mw 6.7 event (Titov et. al. 2003, Walsh et. al. 2003).

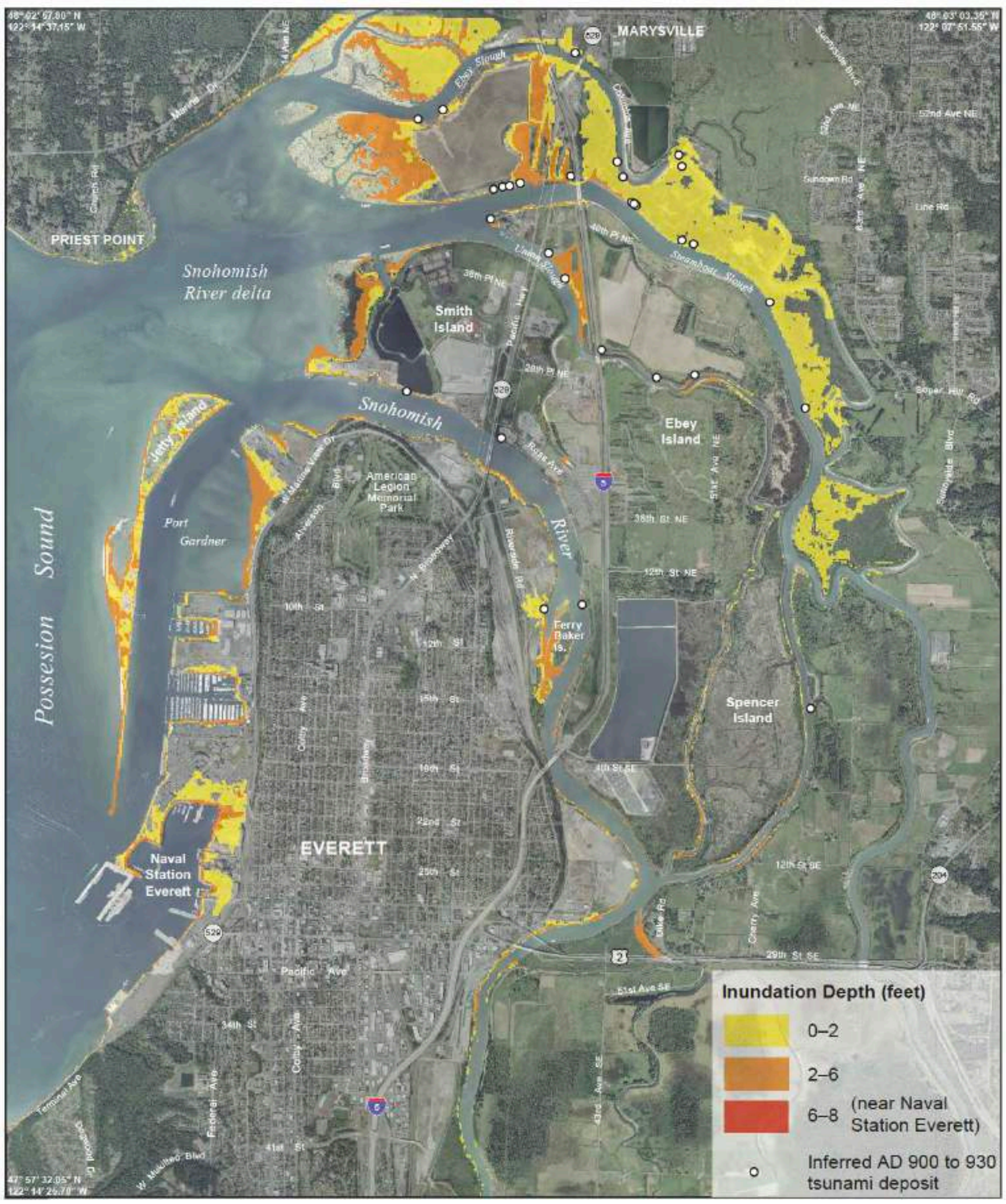

FIGURE TS 4 A: TSUNAMI HAZARD – EVERETT M_W7.3 EVENT (WALSH ET AL. 2014)

FIGURE TS 4 B: TSUNAMI HAZARD – EVERETT M_W6.7 EVENT (WALSH ET AL. 2014)

Tsunami inundation in Neah Bay area (see below) is based on the computer model of waves generated by two different scenario earthquakes, both 9.1M on Cascadia subduction zone (Walsh et. al. 2003). The tsunamis produced by the two scenarios were not distinguishable and are shown as “landward limit of expected inundation”. Modeled lines were smoothed to account for resolution limitations and, in some instances, to place the inundation limit at nearby logical topographic boundaries. The same model was also used for inundation mapping of the Port Angeles area, Port Townsend and Quileute.

FIGURE TS 5: TSUNAMI HAZARD – NEAH BAY AREA (WALSH ET AL. 2003)

FIGURE TS 6: TSUNAMI HAZARD – PORT ANGELES AREA (WALSH ET AL. 2002)

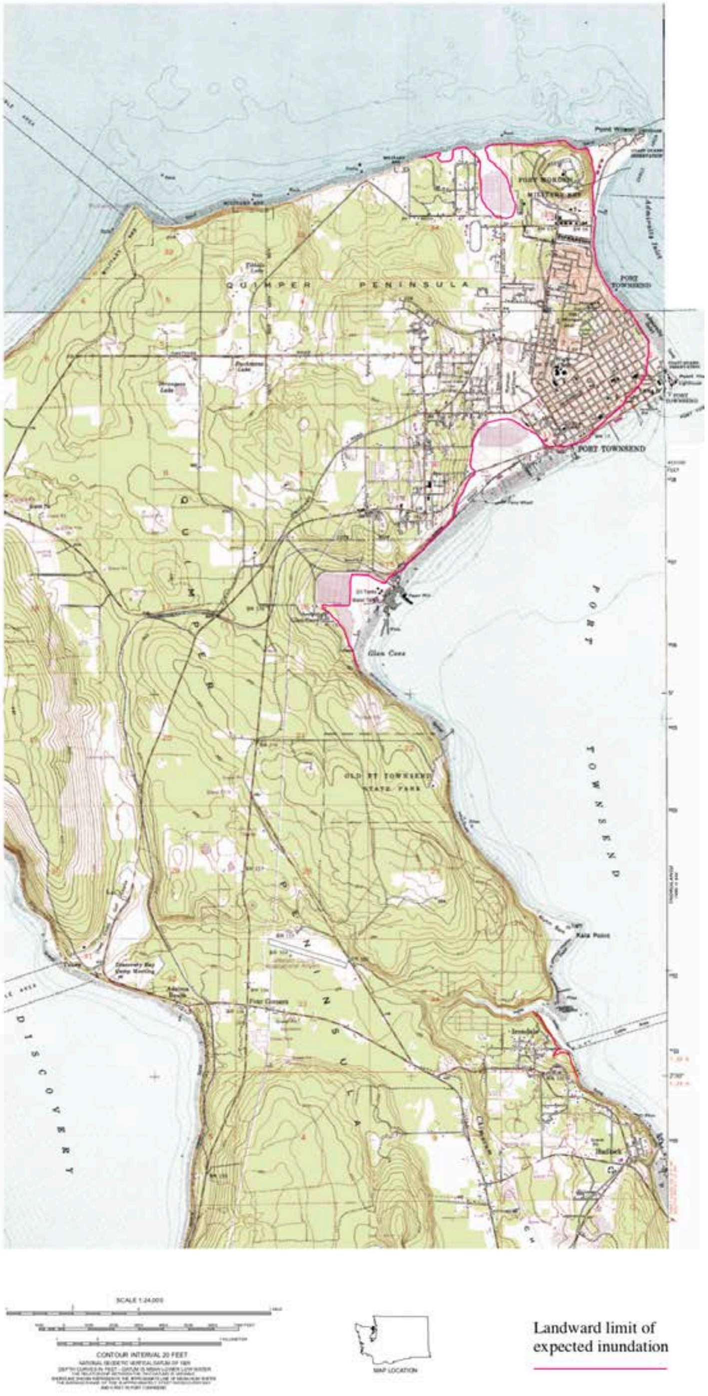

FIGURE TS 7: TSUNAMI HAZARD – PORT TOWNSEND AREA (WALSH ET AL. 2002)

Figure TS 8: Tsunami hazard – Quileute Area (Walsh et al. 2003)

Tsunami inundation shown on the map below for the Elliott Bay area is based on a computer model of waves generated by the Seattle fault (Walsh et. al. 2003)

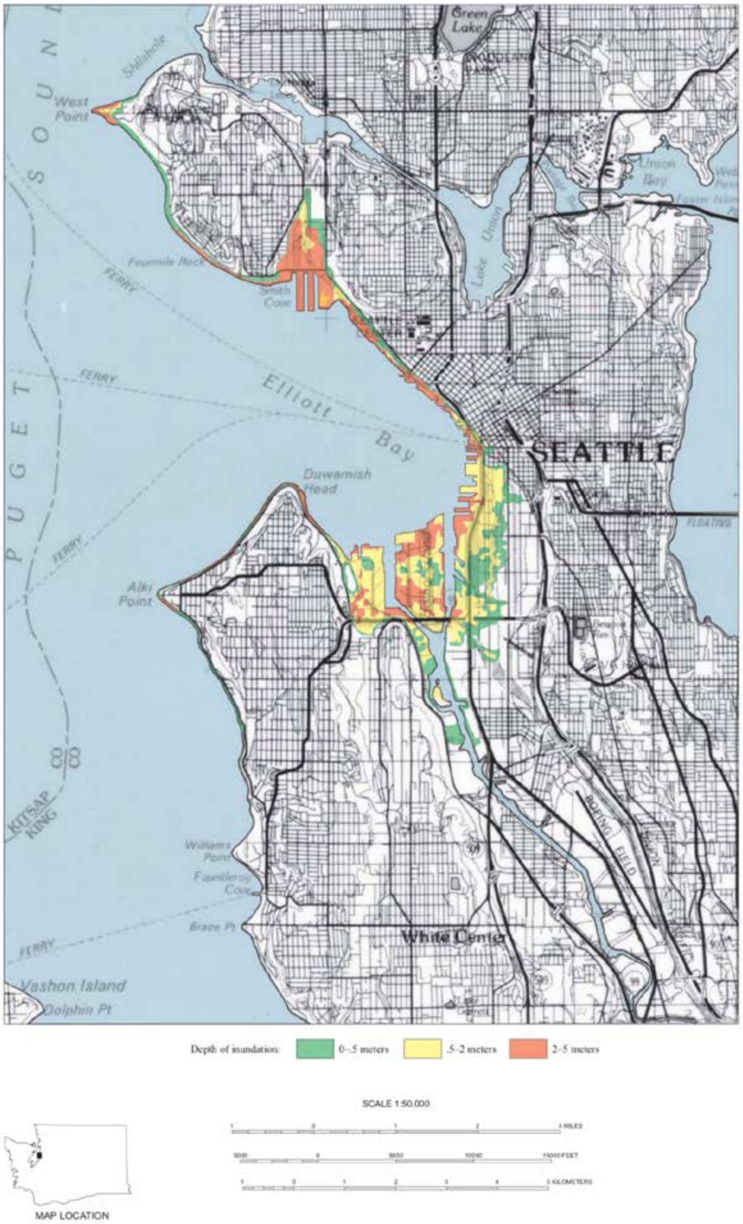

FIGURE TS 9: TSUNAMI HAZARD – ELLIOTT BAY AREA (WALSH ET AL. 2003)

Most modeled studies for Tacoma uses the tsunami simulation generated by a Seattle fault deformation model ~1100 yr B.P. event as a credible worst-case scenario of magnitude 7, and two deformation models for the Tacoma fault (Walsh et. al. 2009). The modeling research showed that Tacoma would be subjected to larger and more damaging waves from a Seattle fault earthquake, even though the Seattle fault is considerably more distant. This is because the Seattle fault traverses Puget Sound in much deeper water and can therefore displace more water.

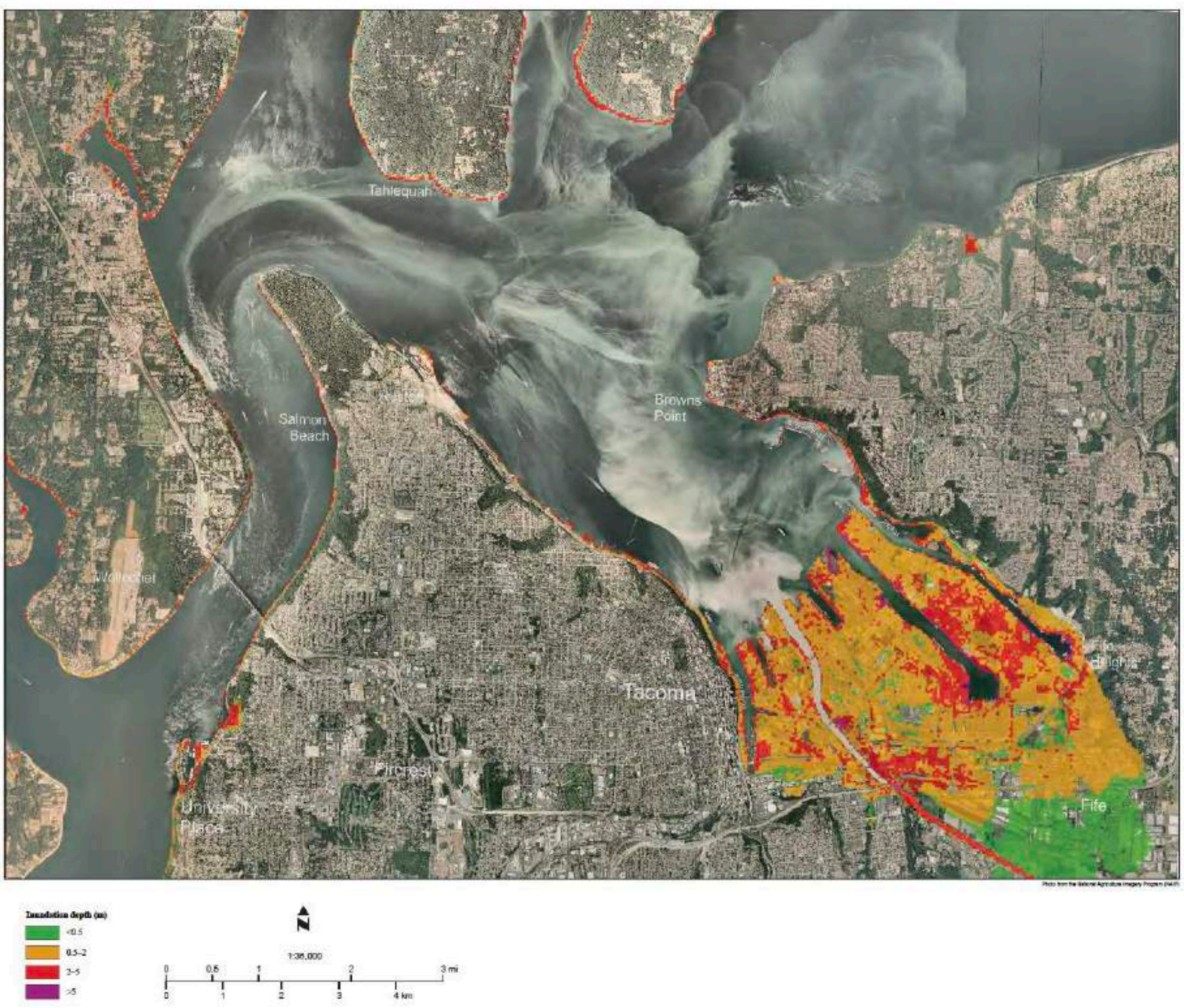

FIGURE TS 10A: TSUNAMI HAZARD – TACOMA: SEATTLE FAULT (WALSH ET AL. 2009)

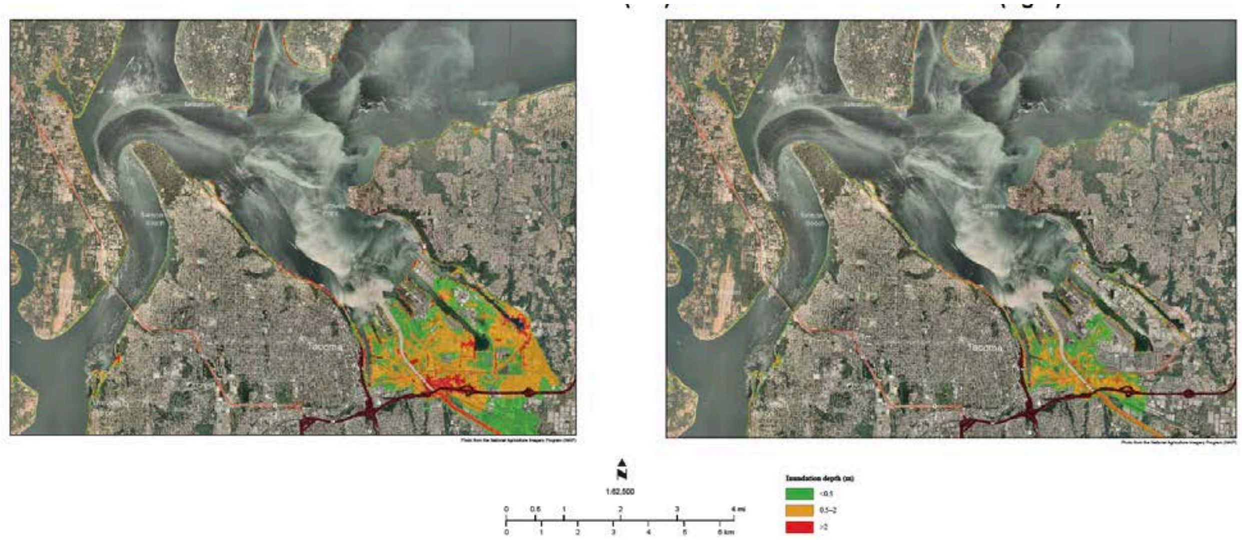

FIGURE TS 10B: TSUNAMI HAZARD – TACOMA: TACOMA FAULT (LEFT); TACOMA-ROSEDALE FAULT (RIGHT) (WALSH ET AL. 2009)

The counties facing the Pacific Ocean are particularly vulnerable to tsunamis caused by a Cascadia Subduction Zone earthquake. The Tsunami Ready® Program in Washington State includes Clallam, Grays Harbor, Jefferson and Pacific counties. This program also includes nine communities including Aberdeen, Hoquiam, Ilwaco, Long Beach, Ocean Shores, Port Angeles, Raymond, South Bend and Westport. Four Indian Tribes/Nations are also participants and include the Lower Elwha, Makah, Quinault and Shoalwater Bay Tribes. The Tsunami Ready® Program is sponsored by the National Weather Service (NWS) that emphasizes exposure awareness.

Tsunamis pose a particular threat for low-lying coastal communities that lack nearby high ground. Such high ground provides a safe gathering area out of the reach of incoming tsunami waves. Modeling has shown that a Cascadia Subduction Zone earthquake could generate a 30ft+ high wave. Because the fault in relatively close to land, evacuation times would be limited to 15-30 minutes. As a result, at least 13 communities along Washington State's Pacific coastline would be vulnerable to significant loss of life due to the lack of reachable high ground for evacuation.

The inundation maps presented here are for a Cascadia Subduction Zone scenario modeled after the AD 1700 event, including extra offshore uplift. These maps, and others depicting all modeled areas on Washington's coast, are available through DNR's Washington Geologic Information Portal.

Tsunamis generated elsewhere on the Pacific Rim are the ones that strike Washington most often. The Washington portion of the Cascadia Subduction Zone produces a great earthquake (magnitude 8 or 9) and associated tsunami often enough for the next of these to have a one-in-ten chance, or better, of occurring in the next fifty years. The frequency of tsunamis from inland sources has not been determined, though expected impacts have been modeled for Seattle, Tacoma and Everett. Many coastal communities throughout the world share this particular vulnerability to tsunamis. Fortunately, vulnerable communities can address the lack of natural high ground by building vertical evacuation structures. When natural high ground is lacking, towers, berms and buildings can provide nearby areas of evacuation. In the 2011 tsunami in Japan, such structures saved thousands of lives.

In 2008, the Federal Emergency Management Agency (FEMA) and the National Oceanic and Atmospheric Administration (NOAA) published “Guidelines for Design of Structures for Vertical Evacuation from Tsunamis” (FEMA P646). This document provided engineering guidance to support planning and development of vertical evacuation structures. Following the devastating 2011 Japanese tsunami, Washington State’s Emergency Management Division (EMD) created the Safe Haven Project working with a variety of partners. In 2012, the Report Project Safe Haven: Tsunami Vertical Evacuation on the Washington Coast was released. The report was a collaboration of the University of Washington Institute for Hazards Mitigation Planning and Research, Washington EMD and DNR, FEMA, NOAA and the United States Geographical Survey (USGS). The report resulted from a public process and recorded proposals for vertical evacuation designs for various communities. Westport in Grays Harbor County was one of the first communities to act on the recommendations. In 2016, Westport completed the construction of the Ocosta Elementary School with a tsunami evacuation refuge located on the roof of the gymnasium. The project was approved by local voters and includes space for up to 2,000 people. This structure is the first of its kind in North America. In 2018, Washington EMD is moving forward with a series of projects to increase tsunami preparedness for coastal communities including building upon the success of the Ocosta project.

Washington State has also experienced tsunamis on the Puget Sound and on inland lakes. The history of these events is covered in the past occurrences section below.

Detection and Preparedness

As tsunamis cannot be predicted, early detection is crucial for reducing the loss of life. In the mid-20th century, national and international coordination around detection of tsunamis began. The Pacific Tsunami Warning Center (PTWC) run by NOAA issues tsunami warnings concerning the Pacific Ocean Basin. The National Tsunami Warning Center (NTWC) also run by NOAA provides tsunami warnings for the west coast. PTWC was founded in 1946 and NTWC in 1967. The International Oceanographic Commission of UNESCO coordinates global tsunami warning systems through the International Tsunami Information Center (ITIC).

In 2001, the United States deployed the DART system. DART stands for Deep-ocean Assessment and Reporting of Tsunamis. Initially this system consisted of 6 surface buoys placed in the ocean and connected by transmission lines to bottom pressure recorders on the ocean floor. These buoys communicate with Tsunami Warning Centers via satellite and register pressure changes due to tsunamis. Since 2001, the technology continues to improve and 39 DART buoys are now deployed along the coasts of all countries bordering the Pacific Ocean Basin. Other nations are deploying these buoys in different ocean basins – there are currently 61 buoys deployed, of which 39 were deployed by the U.S. But the ocean is vast and buoys are few in number and expensive to maintain. Also, the science of measuring and modeling tsunami impacts is still developing.

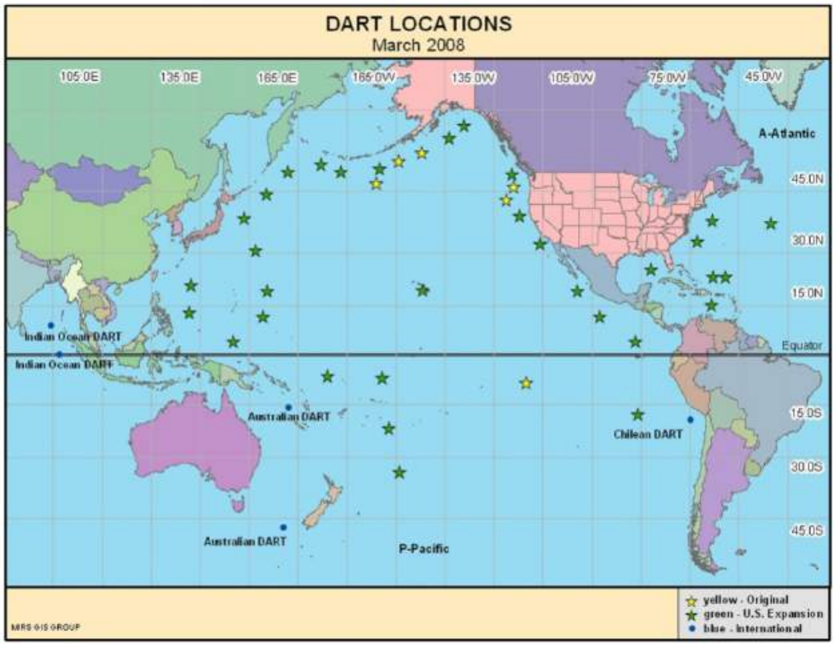

FIGURE TS 11: LOCATION OF NOAA DART INSTRUMENTS IN MARCH 2008

The 2004 Indian Ocean Tsunami and Earthquake resulted in the ramping up of tsunami monitoring and cooperation. In that catastrophe, nearly a quarter million people lost their lives and nearly 2 million people were displaced. This 9.2M earthquake impacted countries around the Indian Ocean Basin but had the largest impacts in Indonesia, Sri Lanka, India and Thailand. There was no tsunami detection system in the Indian Ocean at that time. The 2011 Tohoku earthquake and tsunami generated further support to tsunami monitoring and preparedness.

NOAA's Pacific Marine Environmental Laboratory (PMEL) also uses computer modeling to determine the inundation impacts of particular tsunami scenarios. When tsunamis are detected, NOAA uses detection information to modify modeling and forecast potential impacts to coastal areas. This modeling can help communities to identify the level of threat and take appropriate response measures. In the long-term, this modeling can benefit communities in their land-use planning and infrastructure building.

The National Weather Service (NWS) and the NTHMP established the Tsunami Ready® Program in 2001. Communities can join this voluntary program if they meet a series of guidelines concerning tsunami preparedness. This program helps communities to minimize their losses and access technical and financial resources.

EMD works with NOAA, the National Tsunami Hazard Mitigation Program, and the University of Washington to develop tsunami inundation models. These inundation maps show the potential impacts of tsunami waves on coastal communities. DNR works with Washington state Emergency Management Division (EMD) to produce evacuation maps for communities particularly at risk for tsunamis. EMD, DNR, the United States Geological Survey (USGS) and the National Tsunami Hazard Mitigation Program (NTHMP) produce Tsunami Fact Sheets for local jurisdictions.

Washington has 69 All Hazard Alert Broadcast (AHAB) Sirens deployed along the coast, with 3 more planned by summer 2018. The sirens transmit tsunami warning messages in both English and Spanish and have a flashing warning light. They are activated upon the issuance of an alert from the National Tsunami Warning Center (NTWC). Local jurisdictions also have the ability to activate their sirens at any time. Tsunami warnings may be broadcasted by TV, radio, telephone notifications and texts. NOAA, via the NTWC, pushes out official tsunami watches, advisories, and warnings. Wireless Emergency Alerts and Emergency Alert System messages are activated by the National Weather Service during a tsunami warning. Counties also maintain their own messaging system for which residents can register. Although the warning infrastructure is robust and growing, there may not be time for an official warning so be aware of natural warning signals as described above. Coastal areas at risk for tsunamis will also have signs posted warning of the tsunami threat. In low-lying communities that do not have nearby high ground, planning is underway in some communities to build vertical evacuation shelters.

Past Occurrences

While tsunamis have caused significant damage, deaths and injuries elsewhere in the world, only one significant tsunami struck Washington's Pacific coast in recent history. The 1964 Alaska earthquake generated a tsunami that resulted in more than $640,000 (2004 dollars) in damage. However, geologic investigations indicate that tsunamis have struck the coast a number of times in the last few hundred years.

The most recent Cascadia Subduction Zone earthquake, estimated at magnitude 9, produced a tsunami on Washington's coast in 1700. The tsunami overran Native American fishing camps and left behind telltale sheets of sand on marshes and in lakes along the southern part of the coast. A sand sheet at Discovery Bay in the eastern Strait of Juan de Fuca also probably resulted from the 1700 tsunami.

Japanese written history pinpoints this event to the evening of Jan. 26, 1700. There, the tsunami began in the middle of the night of January 27-28 Japan time and continued until the following afternoon or evening. Its waves drove villagers to high ground, drowned their paddies and crops, damaged their salt kilns and fishing shacks, entered a government storehouse, and ascended a castle moat. It destroyed dozens of buildings, including 20 houses consumed by a fire that the flooding started or spread. It set in motion a nautical accident that sank tons of rice and killed two sailors. It led samurai to give rice to villagers left hungry and to request lumber for those left homeless. The tsunami left a village headman wondering why no earthquake had warned of its coming.

The largest earthquake in recorded history, a magnitude 9.5 earthquake along the coast of Chile, generated a tsunami that struck the Washington coast at Grays Harbor (small waves), Tokeland (2 feet), Ilwaco (two feet), Neah Bay (1.2 feet), and Friday Harbor (0.3 feet). No damage occurred.

The tsunami generated by the March 27, 1964 Alaska earthquake was the largest and best-recorded historical tsunami on the Washington coast. Tsunami wave heights generally were greatest on the south coast and smaller on the north coast. High tides impacted the entire Puget Sound Region, as well as along the Washington coast. In Seattle, tides fluctuated for 30 hours, leaving high tide over 3 feet above normal. In Neah Bay, a high tide was recorded at over 4 feet above what it was supposed to be. Even down in the supposedly protected Hood Canal, the tide was three feet above the projected high tide mark. Additionally, the tsunami was recorded inland in the Strait of Juan de Fuca

(Friday Harbor), Puget Sound (Seattle), and the Columbia River (Vancouver). Observations were made of the tsunami in Grays Harbor County at Westport, Joe Creek, Pacific Beach, Copalis, Grays Harbor City and Boone Creek.

Damages included debris deposits throughout the region, minor damage in Ilwaco, damage to two bridges on State Highway 109, a house and smaller buildings being lifted off foundations in Pacific Beach (the house was a total loss), and damage to the Highway 101 bridge over the Bone River near Bay Center when the Moore cannery building washed against its pilings.

On Nov 15, 2006, a magnitude 8.3 earthquake occurred near the Kuril Islands northeast of Japan. Washington was put into a Tsunami Advisory. A 5-cm tsunami was recorded on the Neah Bay tide gage. However, after the cancellation of the Tsunami Advisory, a train of tsunami waves hit Crescent City, California six hours after the earthquake and destroyed docks, tore about a dozen boats lose from moorings, and sank at least one boat.

An earthquake between the years 900 and 930 raised shores of central Puget Sound by 20 feet between the Duwamish River and Bremerton. The uplift, by also including the floor of Puget Sound, created a tsunami. In Seattle, the tsunami washed across West Point, where it deposited a sheet of sand. Farther north, it deposited a sand sheet at Cultus Bay on southern Whidbey Island and along tributaries of the Snohomish River between Everett and Marysville. Computer simulations of the tsunami show it reaching heights of 20 feet or more at the Seattle waterfront.

Historical accounts among the Snohomish Indian people describe a landslide at Camano Head that sent a large wave south toward Hat Island. Camano Head is at the south end of Camano Island in Puget Sound. According to tribal accounts, the landslide sounded like thunder, buried a small village and created a large volume of dust. The tsunami washed over the barrier beach at Hat Island, destroying homes or encampments and drowning many people. The accounts make no mention of ground shaking, suggesting that the slide was not associated with a large earthquake.

Water in Lake Washington and Puget Sound surged onto beaches two feet above the high-water mark, rocking vessels that had just pulled away from wharves, and causing an elevator in one building to bump against the side of the shaft. The likely cause of this event was two earthquake shocks and submarine landslides.

A small landslide-generated tsunami struck the Point Defiance shoreline in the Tacoma Narrows on April 16, 1949, three days after a magnitude 7.1 earthquake weakened the hillside. According to local newspaper reports, an 11 million cubic yard landslide occurred when a 400-foot high cliff gave way and slid into Puget Sound. Water receded 20-25 feet from the normal tide line, and an eight-foot wave rushed back against the beach, smashing boats, docks, a wooden boardwalk and other waterfront installations in the Salmon Beach area. The slide narrowly missed a row of waterfront homes struck by the tsunami.

Landslides into Lake Roosevelt in eastern Washington generated numerous tsunamis from 1944 to 1953 after the Grand Coulee Dam created the lake on the Columbia River. Most tsunamis generated large waves (30 to 60 feet in height) that struck the opposite shore of the lake, with some waves observed miles from the source. Two tsunamis caused damage:

- Feb. 23, 1951 – A 100,000 to 200,000 cubic yard landslide just north of Kettle Falls created a wave that picked up logs at the Harter Lumber Company Mill and flung them through the mill 10 feet above lake level.
- Oct. 13, 1952 – A landslide 98-miles upstream of Grand Coulee Dam created a wave that broke tugboats and barges loose from their moorings at the Lafferty Transportation Company six miles away. It also swept logs and other debris over a large area above lake level.

Jan. 16, 2009 another landslide–induced tsunami reached a height of about 30 feet and damaged docks at Breezy Bay, Moccasin Bay, Sunset Point and Arrowhead Point.

Another tsunami occurred in 1965. A landslide-triggered tsunami overran Puget Island in the Columbia River near Cathlamet. The landslide originated from Bradwood Point on the Oregon side of the River. The wave killed one person.

The May 18, 1980 eruption of Mount St. Helens caused a massive tsunami in Spirit Lake. The sliding north face of the volcano slammed into the west arm of the lake, raising its surface an estimated 207 feet and sending a tsunami surging around the lake basin as high as 820 feet above the previous lake level. Displaced water rinsed the valley sides clean of timber and sediment, jamming logs and boulders against the landslide debris. In the east arm of Spirit Lake, the tsunami wave reached nearly 740 feet above the old level of the lake, also washing trees off the sides of the valley and into the lake.

Seiches are water waves generated in enclosed or partly enclosed bodies of water such as reservoirs, lakes, bays and rivers by the passage of seismic waves (ground shaking) caused by earthquakes. Sedimentary basins beneath the body of water can amplify a seiche. Seismic waves also can amplify water waves by exciting the natural sloshing action in a body of water or focusing water waves onto a section of shoreline.

In a 2003 paper, researchers at the University of Washington and the National Oceanic and Atmospheric Administration indicate that the geology of the sedimentary basin beneath Seattle amplifies seismic waves from large and distant earthquakes, contributing to the damaging effects of water waves in local enclosed bodies of water.

The November 2002 magnitude 7.9 Denali earthquake in Alaska produced water waves damaging about 20 houseboats in Seattle’s Lake Union, buckling moorings, and breaking sewer and water lines. Sloshing action was reported in swimming pools, ponds and lakes around Seattle. Newspaper reports indicate water waves from the 1964 magnitude 9.2 Alaska earthquake caused similar damage on the lake as well as overtopping the Fairview Hill reservoir and washing gravel into an Aberdeen neighborhood. Sloshing wave action also was reported following the 1949 magnitude 7.1 Olympia earthquake and the 1965 magnitude 6.5 Seattle earthquake.

Researchers believe local amplification of seismic waves could make other urban areas above sedimentary basins in the region particularly vulnerable to seiches or water waves during large earthquakes on the Seattle Fault or the Cascadia Subduction Zone.

Future Probability of Occurrence

Tsunamis generated elsewhere on the Pacific Rim are the ones that strike Washington most often. As a result, it is difficult to estimate the future probability of tsunamis. It is estimated that the earthquake (M8 or M9) in the Washington portion of the Cascadia Subduction Zone will likely produce a significant tsunami with significant damaging and life-threatening impacts along the coastal shoreline communities. Scientists currently estimate that a magnitude 9 earthquake in the Cascadia subduction zone occurs about once every 200-600 years. The last one was in 1700. Investigations have identified 41 Cascadia subduction zone interface earthquakes over the past 10,000 years, which corresponds to one earthquake about every 250 years. Of these 41 earthquakes, about half are M9.0 or greater earthquakes that represent full rupture of the fault zone from Northern California to British Columbia.

The frequency of tsunamis from inland sources has not been determined. A specific rate of occurrence has not been calculated for local earthquakes and landslides that generate tsunamis.

Relationship to Natural Hazards

Tsunamis are a secondary hazard generated by primary hazard events such as earthquakes, volcanic eruptions, landslides or rockfalls, volcano flank collapses, and asteroid impacts. Most commonly, tsunamis are generated during shallow-focus underwater earthquakes that result in sudden rise or fall of the sea floor, displacing large volume of water. Submarine volcanic explosions can also generate strong tsunamis. Such tsunamis are estimated to be extremely large and are likely to result in catastrophic damages. Major, fast moving rockfalls and landslides can also displace large amounts of water when they enter the ocean and generate tsunamis. For example, the 150-meter-high tsunami in Lituya Bay, Alaska was generated when a nearby earthquake caused a large section of cliff to slide into a coastal fjord (Miller 1960).

Tsunamis can lead to significant changes in the marine environment and along the shoreline. Experience from past tsunamis indicates that the environmental damage that they inflict on the coast can lead to enhanced coastal landslides, beach erosion and loss of coastal vegetation cover. Changes due to the causal events such as underwater earthquakes or submarine volcanic eruptions can modify the marine topography which may further enhance the rate of sea level rise and increase costal susceptibility to tidal erosion.

Tsunami Risk Assessment Methodology

Tsunami risk assessment is a challenging task because of the uncertainties involved in predicting the plausible events, and associated wave modelling. For the purpose of this study, tsunami risk analysis is limited to the 15 coastal shoreline counties – Clallam, Grays Harbor, Island, Jefferson, King, Kitsap, Mason, Pacific, Pierce, San Juan, Skagit, Snohomish, Thurston, Wahkiakum and Whatcom Counties.

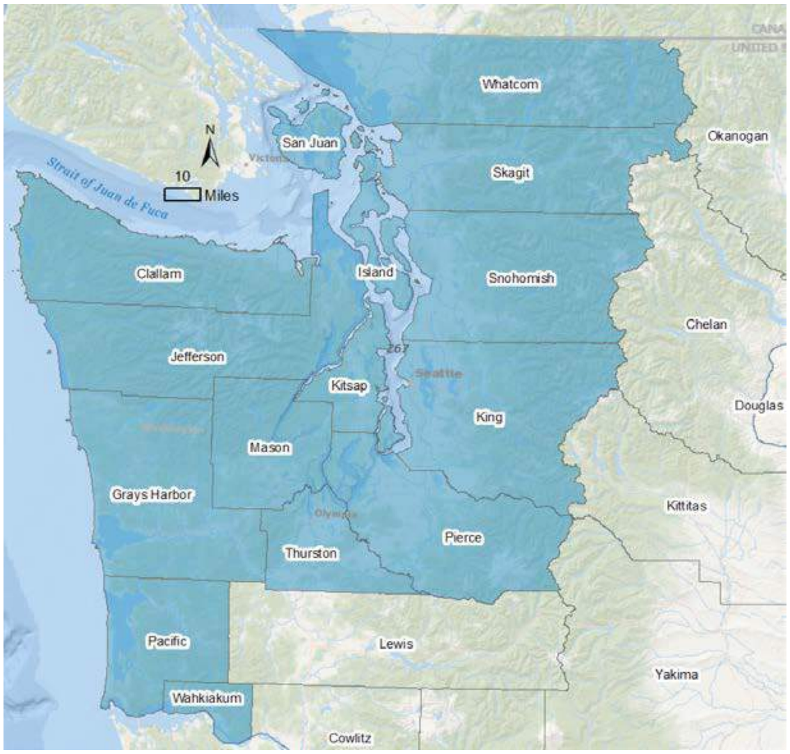

FIGURE TS 12: COASTAL SHORELINE COUNTIES

Assessment of tsunami hazard assessment is based on the multiple tsunami inundation maps prepared by Washington Geological Survey. These include inundation maps for Anacortes-Whidbey Island area, Everett, Bellingham area, Neah Bay area, Elliott Bay area, Port Angeles area, Port Townsend area, Quileute area, Tacoma, and Southern Washington Coast. All coastal communities along the Pacific coast are likely to experience some degree of inundation in case of a tsunami event. Geologic evidence suggests that many of these communities have indeed been impacted by tsunami inundation at some point of time in the past. Because of the uncertainty involved in predicting a tsunami event, WA-DNR uses multiple scenarios to create these inundation zones. However, lack of data on some communities may not necessarily imply absence of tsunami risk, but rather may be the result of modeling limitations or lack of research data.

FIGURE TS 13: TSUNAMI HAZARD LOCATIONS IN WASHINGTON

Area Exposure

Tsunami risk analysis is limited to the coastal shoreline counties in Washington State. The modeled tsunami inundation zones were overlaid with the county map to estimate the area exposed to possible tsunami inundation in each county. Overall, less than 1 percent of the area in 15 coastal shoreline counties is at risk from tsunami inundation. Pacific, Grays Harbor, and Skagit Counties are most at risk from tsunami inundation. Other counties at risk from tsunami inundation include Island, Whatcom, San Juan, Pierce, Clallam, King, Snohomish, and Jefferson Counties. These counties have less than 1 percent of the land area exposed to tsunami inundation. It is reiterated that these exposure estimates are based on the existing tsunami models (discussed in the preceding sections), and as such only reflect modeled extent of land inundation.

Percentage of County Land Area with Tsunami Hazard Exposure	
County	Percent Area
Adams	NA
Asotin	NA
Benton	NA
Chelan	NA

Percentage of County Land Area with Tsunami Hazard Exposure	
County	Percent Area
Clallam	0.22
Clark	NA
Columbia	NA
Cowlitz	NA
Douglas	NA
Ferry	NA
Franklin	NA
Garfield	NA
Grant	NA
Grays Harbor	2.62
Island	0.81
Jefferson	0.04
King	0.19
Kitsap	0.00
Kittitas	NA
Klickitat	NA
Lewis	NA
Lincoln	NA
Mason	0.00
Okanogan	NA
Pacific	4.92
Pend Oreille	NA
Pierce	0.42
San Juan	0.55
Skagit	1.27
Skamania	NA
Snohomish	0.11
Spokane	NA
Stevens	NA
Thurston	0.00
Wahkiakum	0.00
Walla Walla	NA
Whatcom	0.57
Whitman	NA
Yakima	NA
Washington State (15 Coastal Shoreline Counties)	0.93

Population Exposure

Population exposure to tsunamis was estimated by overlaying the tsunami hazard layer over the 2011 developed areas derived from the land cover database. The 2017 estimated population for all census tracts was allocated to respective urban areas and the overlap with landslide exposure was estimated using spatial analysis in Geographic Information System (GIS). Overall, only 1 percent of the population the coastal shoreline counties is estimated to be residing in tsunami inundation zones. However, in Pacific County, 15 percent of the resident population is within the modeled tsunami inundation area. Pierce County has the highest population (16,000) in tsunami inundation areas, followed by King County with 11,000 persons. In Grays Harbor County, almost 9 percent of the county population is exposed to tsunami risks. In all other coastal shoreline counties, development seems to be located outside of the tsunami inundation areas.

It is suspected that the direct population exposure to tsunami inundation seems limited, due to the methodological limitations imposed by data availability. The ultimate tsunami impact will largely depend on the timing of the event. If the event was to occur in summer, on a sunny day, with large number of people on the beach and along the coastline, the resulting impacts would be significantly higher. This temporary increase in population along the beach can range from an addition few hundred to a few thousand persons depending on the season and local weather conditions.

Even though just a small percentage may be impacted by a tsunami directly, those people may very well die. Many coastal communities have insufficient warning time near tsunamis to evaluate. There is limited, or no, access to existing high ground for much of the Long Beach or Ocean Shores communities.

Population Exposure to Tsunamis

County	Total Population (2017 Estimates)	Percentage of Total State Population	Population Exposure to Tsunamis	
			Estimated Population	Percent of County Population
Clallam	74240	1.02	592	0.80
Grays Harbor	72970	1	6435	8.82
Island	82790	1.13	504	0.61
Jefferson	31360	0.43	493	1.57
King	2153700	29.46	11063	0.51
Kitsap	264300	3.62	0	0.00
Mason	63190	0.86	0	0.00
Pacific	21250	0.29	3256	15.32
Pierce	859400	11.76	16080	1.87
San Juan	16510	0.23	147	0.89
Skagit	124100	1.7	4512	3.64
Snohomish	789400	10.8	504	0.06
Thurston	276900	3.79	0	0.00
Wahkiakum	4030	0.06	0	0.00
Whatcom	216300	2.96	1838	0.85
Total Population in 15 Coastal Shoreline Counties	5050440	100	45426	0.90

Vulnerable Population Exposure

The social vulnerability index was created for each of the census tracts using American Community Survey (ACS) 2011-2016 5-year data. Social vulnerability data was first overlaid with developed areas extracted from the 2011 land cover database. Tract level social vulnerability estimates were assigned to respective developed areas in each of the tracts. This data was then overlaid with tsunami hazard layer to identify socially vulnerable developed areas that overlap with tsunami inundation areas.

Overall, almost 33 percent of the state population located in the tsunami inundation zones is also ranked medium or higher on the social vulnerability index. In Clallam County, almost all the population located in the tsunami inundation zone is also ranked medium or higher on social vulnerability Pierce County, which has the largest number of persons in the inundation zone, also has almost 70 percent of this population ranked medium or higher on social vulnerability index. In Pacific County, more than 50 percent of the population residing in tsunami inundation areas is also ranked medium or higher on social vulnerability index. In Snohomish County, almost 20 percent of the population residing in tsunami inundation zone is also ranked medium or higher on the social vulnerability index.

In comparison, King County, which is estimated to have more than 11,000 persons in tsunami inundation areas, does not have any developed areas ranked medium or higher on the social vulnerability index within the inundation zone. This is likely because of the higher land values along the coastline in King County. Also, as highlighted in the preceding section, these estimates do not take into account the seasonal population expected in the coastal shoreline areas. Consequently, the number of persons directly impacted by a tsunami may be much higher depending on the time of the event.

Vulnerable Population Exposure to Tsunamis

County	Population Exposed to Tsunamis (based on 2017 Estimates)		
	Population Exposed to Tsunami	Total Vulnerable Population Exposed	Vulnerable Population (percent of county population at risk)
Clallam	592	570	96.22
Grays Harbor	6435	1101	17.11
Island	504		0.00
Jefferson	493		0.00
King	11063	0	0.03
Kitsap	0		0.00
Mason	0		0.00
Pacific	3256	1733	53.22
Pierce	16080	11198	69.64
San Juan	147		0.00
Skagit	4512		0.00
Snohomish	504	100	19.80
Thurston	0		0.00
Wahkiakum	0		0.00
Whatcom	1838	204	11.12
Washington State	45426	14909	32.82

Built Environment Exposure

The built environment exposure to tsunamis is calculated using the general building stock data (2014) provided by FEMA that contains the building values for all structures in the census tracts. General building stock values used in this analysis are the total structure value of all buildings (except agricultural) in each census tract in 2014 dollars. Building values for all occupancy types were summed for each census tract using only structure values (not content values) and assigned to the developed areas within each tract. These maps were then overlaid on the tsunami hazard layer to estimate the general building stock value within landslide exposure areas. Individual tract level estimates were aggregated to create the county level estimates.

Overall, only 1.21 percent of the State building stock in coastal shoreline counties in locate din tsunami inundation zones. Among all counties, Pacific County has the highest proportion of its general building stock in tsunami inundation zones. Grays Harbor County has almost 9 percent of its general building stock within the tsunami inundation zones. About 4 percent of the general building stock in Skagit County is also at risk from tsunamis.

However, saying only that only about 1 percent of the state's building stock is a risk may understate the threat in that that much of this exposed building stock will be totally destroyed following an event particularly a near tsunami.

Built Environment Exposure to Tsunamis

County	Total Value of General Building Stock (2014)	Exposed to Tsunamis	
		Total Value of General Building Stock (2014)	Percent of County GBS
Clallam	$2,427,219.00	$18,704.69	0.77
Grays Harbor	$1,162,104.00	$102,480.90	8.82
Island	$2,895,464.00	$16,497.40	0.57
Jefferson	$1,137,144.00	$17,742.09	1.56
King	$362,698,022.00	$1,862,469.16	0.51
Kitsap	$17,267,166.00	$0.00	0.00
Mason	$608,531.00	$0.00	0.00
Pacific	$125,715.00	$19,264.64	15.32
Pierce	$62,547,883.00	$1,168,440.28	1.87
San Juan	$225,856.00	$2,008.65	0.89
Skagit	$5,389,339.00	$195,920.40	3.64
Snohomish	$52,406,666.00	$33,478.24	0.06
Thurston	$9,798,392.00	$0.00	0.00
Wahkiakum	$1,649.00	$0.00	0.00
Whatcom	$15,241,051.00	$128,859.46	0.85
Total – Washington Coastal Shoreline Counties	$533,932,201.00	$6,439,018.09	1.21

Critical Infrastructure Exposure

Critical infrastructure facilities that lie within the tsunami inundation zones will be directly impacted by tsunami waves. While the nature and degree of impact will largely depend on the size of the tsunami event and the physical details of the facility, spatial overlay analysis can enable prioritization of site specific hazard mitigation studies. Location of 12 critical infrastructure facilities including airports (23), communication towers (16097), dams (268), education facilities (5331), electric substations (1392), hospitals (147), power plants (146), public transit stations (60), railroad bridges (1619), railway stations (317), urgent care facilities (113), and weather radar stations (2), were derived from the Homeland Security Foundation Level Database (HIFLD). This data was overlaid with the tsunami hazard zones to identify facilities located in landslide areas. This analysis refers to point data and not critical infrastructure represented by networks such as roads and rail corridors. A number of major transportation corridors along the coast may likely include segments that will be impacted by a tsunami event. However, due to data limitations this network analysis has not been considered in this analysis.

Spatial overlay analysis reveals that only 3.86 percent of the critical infrastructure facilities located in the coastal shoreline counties are located within the tsunami inundation zones. Almost 30 percent of the critical infrastructure facilities in Grays Harbor County are at risk from Tsunamis. In Pacific County 16 percent of critical infrastructure facilities are located in tsunami inundation zones. Out of the 1,130 critical infrastructure facilities mapped in Pierce County, 79 (7 percent) are at risk from tsunamis. While this assessment does highlight tsunami risk to facilities on spatial location, it is highlighted that specific risk to each facility results from the combination of the event characteristics (which are difficult to predict) and the site-level facility characteristics.

Critical Infrastructure Exposure

County	Number of Critical Infrastructure Facilities	In Tsunami Inundation Areas	
		Number of Critical Infrastructure Facilities	Percent of Critical Infrastructure Facilities
Clallam	273	11	4.03
Grays Harbor	377	110	29.18
Island	104	1	0.96
Jefferson	197	3	1.52
King	2761	55	1.99
Kitsap	451	0	0.00
Mason	152	0	0.00
Pacific	152	25	16.45
Pierce	1130	79	6.99
San Juan	98	0	0.00
Skagit	474	8	1.69
Snohomish	787	5	0.64
Thurston	462	0	0.00
Wahkiakum	17	0	0.00
Whatcom	613	14	2.28
Total in Washington Coastal Shoreline Counties	8048	311	3.86

State Operations and Facilities Exposure

The list of state owned (9,415) and leased facilities (1,039) was obtained from 2017 Facilities Inventory System Report produced by Office of Financial Management (detailed list included in Appendix). These facilities were geo-located based on the addresses provided in the facilities inventory report and then overlaid with tsunami hazard layer.

Overall, only 2 percent of the State-owned facilities in coastal shoreline counties are located in tsunami inundation zones. King and Pierce Counties have most number (24 each) at risk from tsunamis. In Pacific County, only 8 of the 233 State-owned facilities are located in tsunami inundation zones. Out of the 109 State-leased facilities in coastal shoreline counties only 29 (less than 5 percent) are at risk from tsunamis. In Grays Harbor County, 9 of the 12 state-leased facilities are located in tsunami inundation zone. This analysis indicates that majority of the state facilities are not likely at risk from tsunamis in the coastal shoreline counties. However, specific tsunami risk to each facility will ultimately be a function of event characteristics and local site characteristic include implementation of any local hazard mitigation actions.

State Owned and Leased Facilities Exposure

County	State Owned Facilities	State Leased Facilities	In Tsunami Inundation Areas			
			State Owned Facilities	Percent of State Owned Facilities	State Leased Facilities	Percent of State Leased Facilities
Clallam	183	12	4	2.19	2	16.67
Grays Harbor	224	13	5	2.23	9	69.23
Island	269	6	4	1.49	0	0.00
Jefferson	394	5	12	3.05	2	40.00
King	1120	226	24	2.14	4	1.77
Kitsap	269	15	0	0.00	0	0.00
Mason	244	7	0	0.00	0	0.00
Pacific	233	6	8	3.43	4	6.67
Pierce	865	54	24	2.77	2	3.70
San Juan	282	5	9	3.19	0	0.00
Skagit	286	15	8	2.80	0	0.00
Snohomish	270	71	5	1.85	0	0.00
Thurston	431	166	0	0.00	0	0.00
Wahkiakum	22	0	0	0.00	0	0.00
Whatcom	283	32	6	2.12	4	12.50
Total in Washington Coastal Shoreline Counties	5375	633	109	2.03	29	4.58

First Responder Facilities Exposure

Locations of fire stations, law enforcement buildings, and emergency medical stations in the State were identified from the Homeland Security Foundation Level Database (HIFLD). Using ESRI ArcMap geocoding services 1,268 fire stations, 332 law enforcement agencies, and 1,162 EMS stations (including those co-located with fire stations) were located on the state map. Of the 666 fire stations located in coastal shoreline counties, only 26 are located in tsunami inundation zones. Pacific and Grays Harbor County have maximum number of fire stations (9 each) at risk from tsunamis. In Pierce County, 2 of the 99 fire stations are located in tsunami inundation zone. Clallam, Skagit, Snohomish, and Whatcom counties, each has one firs station at risk from tsunamis. In Pacific County 4 of 5 law enforcement buildings are located in tsunami inundation zone. In Grays Harbor County, 4 of the 9 law enforcement buildings are located in tsunami inundation zone. In Jefferson and King Counties only 1 (each) law enforcement building is at risk from tsunamis. Grays Harbor County (8) has the maximum number of EMS facilities located in tsunami inundation zone. In Pacific County, 4 of the 10 EMS facilities are at risk from tsunamis.

However, although overall, less than 2 percent of the EMS facilities located in coastal shoreline counties are located in tsunami inundation zones, those that are, will most likely not be functional following an event. And, redundant assets are not available to many of these impacted coastal populations.

First Responder Facilities Exposure to Tsunamis

County	Fire Station			Law Enforcement			EMS		
	Total Number of Facilities	In areas Exposed to Tsunamis		Total Number of Facilities	In areas Exposed to Tsunamis		Total Number of Facilities	In areas Exposed to Tsunamis	
		Number of facilities	Percent Facilities		Number of facilities	Percent Facilities		Number of facilities	Percent Facilities
Clallam	22	1	4.55	5	0	0.00	24	3	12.50
Grays Harbor	32	9	28.13	9	4	44.44	20	8	40.00
Island	10	0	0.00	4	0	0.00	9	0	0.00
Jefferson	12	0	0.00	4	1	25.00	13	0	0.00
King	159	2	1.26	60	1	1.67	161	2	1.24
Kitsap	47	0	0.00	6	0	0.00	49	0	0.00
Mason	46	0	0.00	3	0	0.00	47	0	0.00
Pacific	16	9	56.25	5	4	80.00	10	4	40.00
Pierce	99	2	2.02	29	0	0.00	101	2	1.98
San Juan	4	0	0.00	1	0	0.00	5	0	0.00
Skagit	39	1	2.56	6	0	0.00	40	1	2.50
Snohomish	74	1	1.35	23	0	0.00	73	1	1.37
Thurston	47	0	0.00	17	0	0.00	55	0	0.00
Wahkiakum	9	0	0.00	1	0	0.00	5	0	0.00

Whatcom	50	1	2.00	10	0	0.00	54	1	1.85

Washington State Risk Index for Tsunamis (WaSRI-TS)

The tsunami risk index (WaSRI-TS) for each of the coastal shoreline counties is estimated as the average of the standardized rank of tsunami exposure assessment for population, vulnerable populations, built environment, critical infrastructure facilities, state facilities and first responder facilities. The individual exposure assessment values were categorized into 5 classes (1: Low, 2: Medium-Low, 3: Medium, 4: Medium-High, and 5: High) using z-score transformation (standard deviations from the mean).

Classification Schema for Standardized Exposure Assessment Values

Standard Deviation	Classification Rank
>1	High (5)
0.50 to 1.0	Medium-High (4)
0.5 to -0.5	Medium (3)
-0.5 to -1	Medium-Low (2)
< -1.0	Low (1)

The tsunami risk index (WaSRI-TS) is the mean of these individual exposure rankings. While similar assessments were also done for economic consequences (described in the next sections), these specific rankings were not included in the estimation of the tsunami risk index. Economic consequence rankings were not included because of data quality limitations. Economic consequences estimates are based on overall county data. Including them in the index is likely to result in biased estimation of landslide risk. Additionally, the direct and indirect economic consequences from a tsunami events are likely span across a variety of economic sectors and as such are difficult to estimate. Similarly, a tsunami event is likely to have devastating consequences for the coastal areas and the marine environment. The diversity and complexity of the possible ecological impacts associated with a tsunami make it difficult to undertake a comprehensive ecological assessment as part of this risk analysis.

Tsunami risk analysis for the coastal shoreline counties of the State reveals that Grays Harbor and Pacific Counties are at highest risk from tsunamis. Kitsap, Mason, Thurston, and Wahkiakum counties are estimated to be at lowest risk from tsunamis. Island King, San Juan, and Snohomish counties are estimated to be at medium-low risk from tsunamis. Clallam County is estimated be at medium-high risk from tsunamis. Four counties – Jefferson, Pierce, Skagit and Whatcom counties are estimated to be at medium risk from tsunamis. It is important to note that this risk assessment tis based on specific scenarios. Lower risk in some of the coastal shoreline counties may be due to absence of tsunami inundation maps. These shoreline counties may not be at risk in the specific scenarios utilized for this risk assessment but may have higher risk in yet unpublished models. It is, therefore, important to interpret the results of this analysis within the limitations of data availability and models utilized for assessment.

Tsunami Risk Index (WaSRI TS) and Constituent Tsunami Exposure Ranks for Each County

County	Area	Population	Vulnerable Population	Built Environment	Critical Infrastructure	State Facilities	First Responder Facilities	Tsunami Risk (WaSRI TS)
Clallam	Medium-Low	Medium-Low	High	Medium-Low	Medium	Medium	Medium-High	Medium-High
Grays Harbor	High	High	Medium-High	High	High	High	High	High
Island	Medium-Low	Medium-Low	Low	Medium-Low	Medium-Low	Low	Low	Medium-Low
Jefferson	Medium	Medium	Low	Medium	Medium-Low	Medium -High	Medium	Medium
King	Medium-Low	Medium-Low	Medium-Low	Medium-Low	Medium	Medium -Low	Medium-Low	Medium-Low
Kitsap	Low	Low	Low	Low	Low	Low	Low	Low
Mason	Low	Low	Low	Low	Low	Low	Low	Low
Pacific	High	High	High	High	High	High	High	High
Pierce	Medium-High	Medium	High	Medium	Medium-High	Medium -Low	Medium-Low	Medium
San Juan	Medium	Medium-Low	Low	Medium	Low	Medium	Low	Medium-Low
Skagit	Medium-High	Medium-High	Low	Medium-High	Medium-Low	Medium -Low	Medium	Medium
Snohomish	Medium-Low	Medium-Low	Medium-High	Medium-Low	Medium-Low	Low	Medium-Low	Medium-Low
Thurston	Low	Low	Low	Low	Low	Low	Low	Low
Wahkiakum	Low	Low	Low	Low	Low	Low	Low	Low
Whatcom	Medium	Medium-Low	Medium	Medium	Medium	Medium -High	Medium	Medium

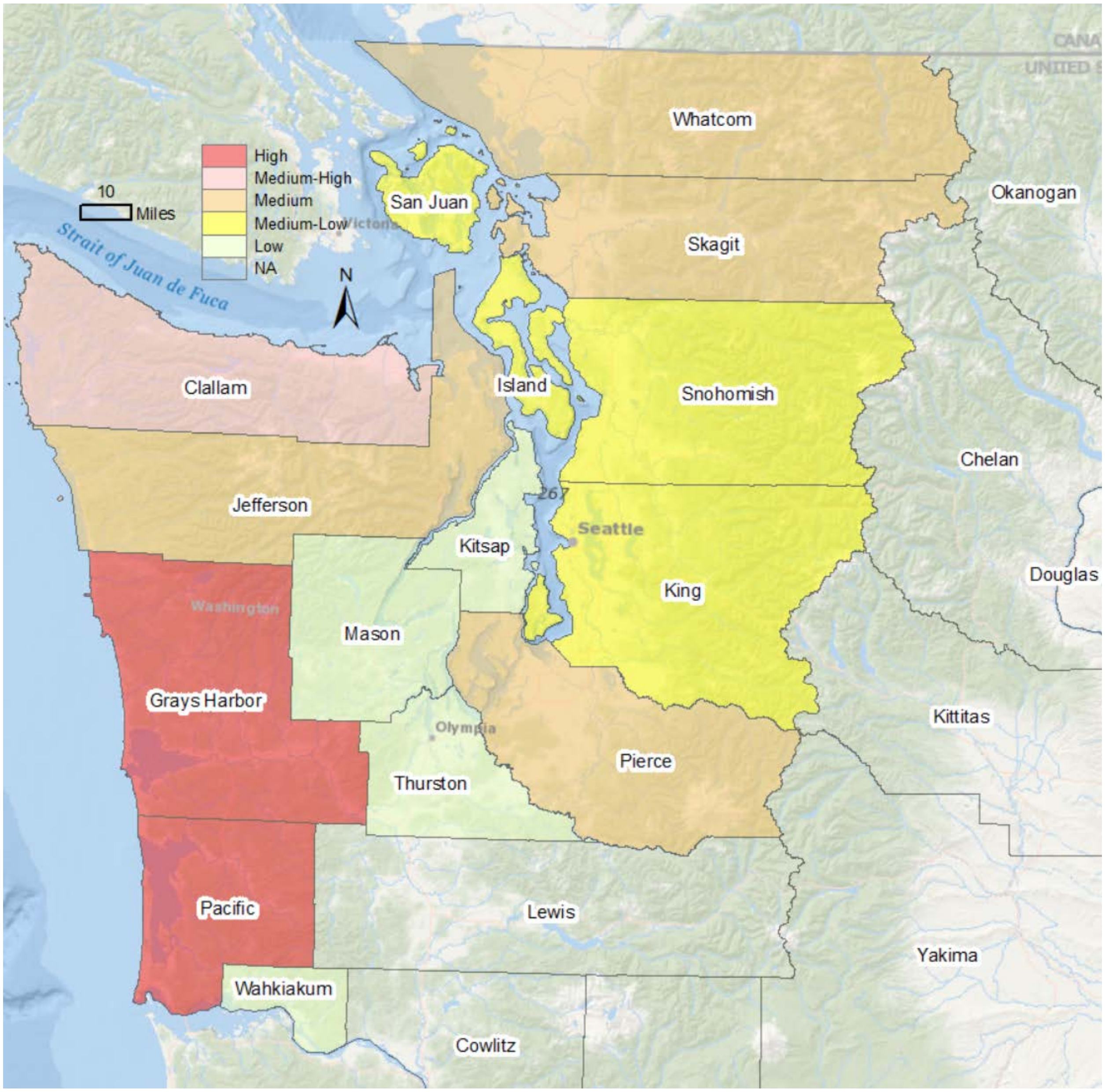

FIGURE TS 14: TSUNAMI RISK DISTRIBUTION (WASRI-TS)

Economic Consequences

The economic activity data was derived from National Association of Counties. This dataset provides the county level estimates of Gross Domestic Product (GDP) for 2016. The two coastal shoreline counties ranked high on the tsunami risk index contribute less than 1 percent of the State Gross Domestic Product. King County, the top contributor to the State GDF is ranked medium-low for tsunami risks. Pierce County, the next significant coastal shoreline county, is ranked medium for tsunami risk. While this data provides a simplistic overview of the relative tsunami impacts in each of the coastal shoreline counties, it does not provide a full picture.

As per the tsunami impact study of the open-ocean and Strait of Juan de Fuca (Wood and Soulard 2008), the businesses in the tsunami inundation zone generated $4.6 billion annually in sales volume. In the same study, researchers found that majority of the business in many of the coastal communities depended on the coast in some form.

In case of a tsunami event, these businesses would likely be lost and lead to increased unemployment in the region. Losses would continue to mount for subsequent years as it would take significant time for the communities and businesses to recover from tsunami impact. The same study estimated that total economic losses in Washington State would likely exceed $6 billion in the first year itself. This is equivalent to approximately 2 percent of the State GDP of $346 billion in 2007.

Tsunami Risk (WaSRI TS) and County GDP 2016

County	Tsunami Risk Index (WaSRI TS)	GDP 2016 (in Mil.)
Clallam	Medium-High	$2,573.06
Grays Harbor	High	$2,237.44
Island	Low	$2,796.80
Jefferson	Medium	$867.23
King	Medium-Low	$230,344.61
Kitsap	Low	$12,082.18
Mason	Low	$1,566.21
Pacific	High	$637.45
Pierce	Medium	$41,280.80
San Juan	Medium-Low	$602.88
Skagit	Medium	$5,705.48
Snohomish	Medium-Low	$39,378.97
Thurston	Low	$12,865.29
Wahkiakum	Low	$93.41
Whatcom	Medium	$10,068.49

Risk to Environment

Tsunamis can lead to significant ecological damage in the coastal regions. Experiences from past tsunamis indicates that some of the key ecological impacts inflicted on the coastline include saltwater intrusion into the groundwater table, irreversible changes to the coastal vegetation, and even the disappearance or relocation of the beaches. Depending on the size of the tsunami event, the resulting debris can, itself, become an environmental hazard. Hazard materials from the coastal industries and other on-shore development can be released into the ocean and deposited on land. Contamination of soil and water is a major threat from tsunamis. This includes increase in salinity of the rivers, wells, lakes and ground water aquifers. Salt-water intrusion, leaking septic tanks and debris contaminated water wells quickly impacted the groundwater that lies just below the surface. Salination and debris contamination may also lower soil fertility for years.

Tsunamis may also result in loss of natural ecosystem. Coral reefs, mangroves, wetlands, and aquaculture farms can be significantly damaged. The 2004 tsunami off the coast of Indonesia is estimated to have damaged 20 percent of sea grass beds, 30 percent of coral reefs and 25-35 percent of wetlands, and 50 percent of sandy beaches of the west coast of Indonesia; in Thailand, 15 to 20 percent of the coral reefs were affected by the tsunami primarily due to siltation and sand infiltration; in the Nicobar Islands 51-100 percent of mangrove systems, 41-100 percent of coral reefs, and 6.5-27 percent of forest ecosystems were damaged (Srinivas and Nakagawa 2008, Sivakumar 2009, Szczuciński et. al. 2005). Tsunamis can also result in nutrification of coastal waters by transporting materials from land back to sea. These heavy nutrients and trace elements can lead to phytoplankton blooms and increase in the secondary consumer populations. Hypoxic conditions are also possible with extreme nitrification.

The overall impact on the biological communities due to tsunamis can be characterized as medium-high. Some studies suggest that it took more than four years after the 2004 tsunami for intertidal and offshore communities to recover with similar species and number of individuals (Szczuciński et. al. 2005). Some researchers have suggested that some of the impacted coastal systems can be expected to recovery rapidly because they are naturally highly variable (Lotze et al. 2006).

Coast lands may also be redistributed. Loosely compacted sands from Ocean Shores and Long Beach in particular, may be washed into the Grays Harbor and Willipa Bay. These high ground peninsulas may become salt marches and low islands following a Cascadia earthquake.

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Volcano Risk Summary

<table>
<tr><th>Washington State Risk Index for Volcano (WaSRI-V)</th><th>MEDIUM</th></tr>
<tr><td>LIKELIHOOD</td><td>LOW</td></tr>
<tr><td colspan="2">Based on a U.S. Geological Survey (USGS) study, there is a 1 in 500 chance that portions of 2 counties will receive 10 centimeters (4 inches) or more of volcanic ash from any Cascades volcano in any given year.</td></tr>
<tr><td>HAZARD AREA</td><td>LOW</td></tr>
<tr><td colspan="2">About 6% of the land area is at direct risk from possible lahars.</td></tr>
<tr><td>POPULATION</td><td>MEDIUM</td></tr>
<tr><td colspan="2">About 11% of the State population resides in areas likely to be impacted by lahars. However, a significantly higher number of persons are likely to be affected by volcanic ash which can spread over long distances.</td></tr>
<tr><td>VULNERABLE POPULATION</td><td>MEDIUM</td></tr>
<tr><td colspan="2">Less than 5% of the State population resides in areas exposed to lahar hazards. However, elderly, children and others with medical conditions are likely to be significantly affected within a much larger areas of ashfall.</td></tr>
<tr><td>BUILT ENVIRONMENT</td><td>MEDIUM-LOW</td></tr>
<tr><td colspan="2">About 11% of the total State General Building Stock is in areas with 1% or 0.2% annual chance of flooding.</td></tr>
<tr><td>CRITICAL INFRASTRUCTURE</td><td>LOW</td></tr>
<tr><td colspan="2">About 8% of the critical infrastructure facilities are located in areas exposed to lahars.</td></tr>
<tr><td>STATE FACILITIES</td><td>LOW</td></tr>
<tr><td colspan="2">Less than 6% of State Owned facilities are located in areas exposed to lahars.
Less than 8% of the State Leased facilities are located in areas exposed to lahars.</td></tr>
<tr><td>FIRST RESPONDERS</td><td>MEDIUM- LOW</td></tr>
<tr><td colspan="2">7% of the Fire Stations are located in areas exposed to lahars.
10% of the Law Enforcement facilities are located in areas exposed to lahars.
8% of the EMS facilities are located in areas exposed to lahars.</td></tr>
<tr><td>ECONOMIC CONSEQUENCES</td><td>MEDIUM-LOW</td></tr>
<tr><td colspan="2">Counties ranked medium or higher on WaSRI-V account for 18% of the State Gross Domestic Product.</td></tr>
<tr><td>ENVIRONMENTAL IMPACTS</td><td>MEDIUM-HIGH</td></tr>
<tr><td colspan="2">Volcanic eruptions will significantly impact the local environmental resources. Lahars and pyroclastic flows are devastating to all vegetation in their paths. Ash deposits are also likely to negatively impact the local ecological diversity</td></tr>
</table>

Hazard Description

Volcanism is caused by rise of magma to the Earth's surface. The properties of magma changes as it ascends due to the changes in pressure and temperature; as the pressure and temperature decrease closer to Earth's surface, minerals in the magma become solid crystals, changing the chemistry of the magma. These changes in the magma will ultimately determine the nature and explosivity of the eruption (Rubin 1995). There are five active volcanoes in Washington, seven other volcanoes, and several more volcanic fields in the rest of the Pacific Northwest. These volcanoes tend to erupt explosively and can cause significant damage throughout the region. High-speed, pyroclastic flows of hot ash and rock, lava flows, and landslides can destroy homes and infrastructure within a few miles of the eruption. Enormous mudflows of ash, debris, and melted ice—called lahars—can devastate low-lying areas more than 50 miles away.

There are several hazards caused by volcanic action that can be harmful to life and property. These include lava flows, lahars, ash falls, debris avalanches, and pyroclastic flows. Lava flows rarely threaten human life because lava usually moves slowly. How quickly lava flows is controlled by the steepness of the slope it is on (steeper slopes = faster flows), and the chemical composition of the lava itself. Typical lava in the cascades, called Andesite, or Dacite, is more viscous – resistant to flow – because it has a higher silica content, and might flow only a few centimeters per hour. – Lava flows typically seen in Hawaii, are a lava type called basalt, with a very low silica content, and it may travel at speeds of several miles per hour. Although slow, lava flows bury, crush, cover, and burn everything in their path. Sometimes lava melts ice and snow to cause floods. Lava flows can dam rivers to form lakes that might overflow causing floods.

Lahars are mudflows made up of volcanic debris. They can form in a number of situations, such as through rapid melting of snow and ice during an eruption, from heavy rainfall on loose volcanic debris, when a volcano erupts through a crater lake, or when a crater lake drains because of overflow or wall collapse (Francis 1993). Lahars flow like liquids, but because they contain suspended material, they usually have a consistency similar to wet concrete. Lahars can travel at speeds of over 50 mph and reach distances dozens of miles from their source. If a volcanic eruption generated them, they may retain enough heat be 140-160°F when they come to rest. Lahars are extremely destructive. They will either bulldoze or bury anything in their path, sometimes in deposits dozens of feet thick. Whatever cannot get out of a lahar's path will either be swept away or buried. Lahars can, however, be detected in advance by remote sensors, which gives people time to reach high ground; they can also sometimes be channeled away from buildings and people by concrete barriers, although it is impossible to stop them completely.

Ashfall is the most widespread and frequent volcanic hazard. All explosive volcanic eruptions generate tephra, fragments of pulverized rock produced when magma or rock is explosively ejected from the volcano. The largest fragments, blocks and bombs (>2.5 inches in diameter), can be expelled with great force but are closest to the vent. Lapilli-sized material (0.24-2.5 inches diameter) can be carried upward within a volcanic plume and downwind in a volcanic cloud then fall to the ground as the eruption cloud cools. The smallest material, volcanic ash (<2 mm (~0.1 inches) diameter) is both easily convected upward within the plume and carried downwind for very long distances; as it falls out of suspension it can potentially affect communities and farmland over wide areas of land, hundreds of miles away from the volcanic vent. Ashfall rarely endangers human lives, but it can have devastating effects on vehicles and aircraft, flat-roofed buildings, and people with serious respiratory illnesses. As a result of its fine-grained abrasive character and widespread distribution by wind, ashfall and volcanic ash clouds are a major hazard to aviation. Washington's two most explosive volcanoes are Mt. St. Helens and Glacier Peak. An example of how large an area ash fall may impact is seen in the diagram below.

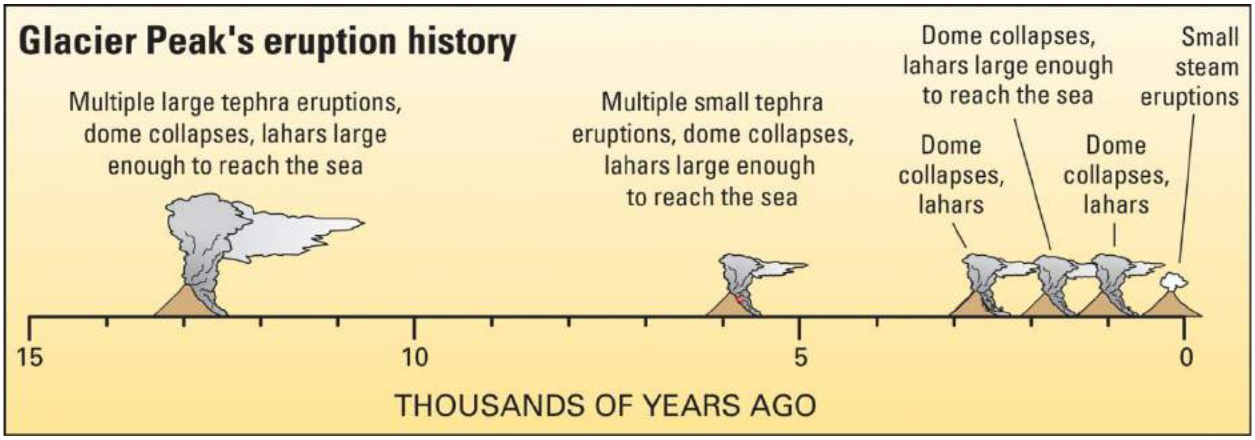
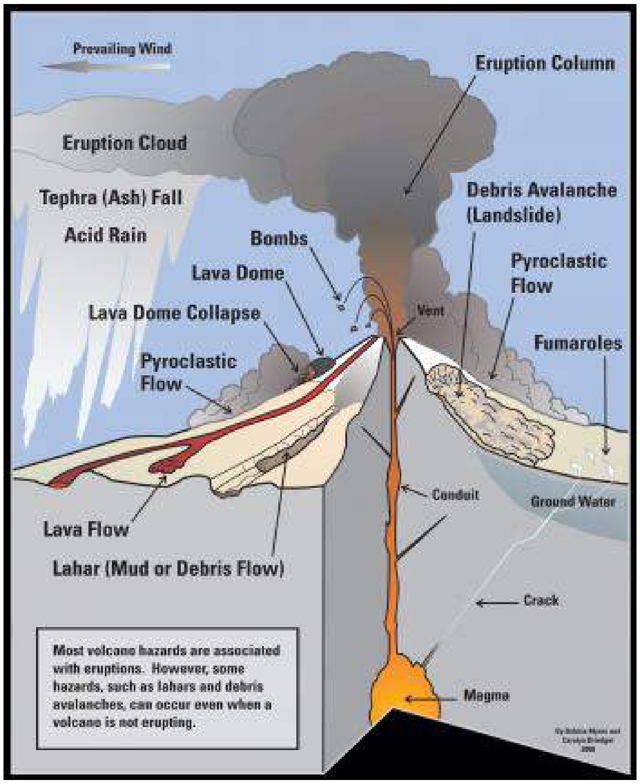


FIGURE 1: GLACIER PEAK ERUPTION HISTORY (SOURCE: USGS)

Pyroclastic flows move fast and destroy everything in their path. Pyroclastic flows contain a high-density mix of hot lava blocks, pumice, ash and volcanic gas. They move at very high speed down volcanic slopes. Most pyroclastic flows consist of two parts: a lower (basal) flow of coarse fragments that moves along the ground, and a turbulent cloud of ash that rises above the basal flow. Ash may fall from this cloud over a wide area downwind from the pyroclastic flow. Pyroclastic flows can form in different ways:

- Collapse of eruption column: during a highly explosive eruption, the column ejected upwards into the atmosphere cools, becoming too dense to maintain upward momentum.
- "Boiling over" from eruptive vent: during an explosive eruption, material is erupted without forming a high plume and rapidly moves down slope.



Most volcano hazards are associated with eruptions. However, some hazards, such as lahars and debris avalanches, can occur even when a volcano is not erupting.

FIGURE V 1: VOLCANO HAZARDS
(SOURCE: MEYERS AND DRIEDGER 2008)

- Collapse of lava domes or flows: The fronts of lava flows or domes can become so steep that they collapse due to gravitational force.

Pyroclastic flows vary considerably in size and speed, but even relatively small flows can destroy buildings, forests, and farmland. On the margins of pyroclastic flows, death and serious injury to people and animals may result from burns and inhalation of hot ash and gases. Pyroclastic flows generally follow valleys or other low-lying areas but, this is not always the case, which has led to a number of fatalities in the past. Depending on the volume of rock debris carried by the flow, they can deposit layers of loose rock fragments to depths ranging from less than three feet up to about 700 feet.

Major types of volcanic hazard, their effects and extents are listed in the table below. The occurrence and scale of volcanic hazards are inversely related, with small events occurring more frequently (10-20 a month), and larger events occurring every hundred years or so (Pyle 1998).

Summary of the Effects and Extents of Major Volcanic Hazards (Source: Sparks and Aspinall 2004)

Hazard	Threat to life	Threat to Property	Areas affected
Ash and pumice fall	Low except near vent; high for aviation	Depends on size; can lead to roof collapse, bomb damage, fire	Local, Regional, National, International
Pyroclastic flows	Very high	Very high	Local, Regional, National, International
Lava flows	Low	Very high	Local
Lahars/flooding	High to moderate	High	Local, Regional
Gases/ducts/acid rain	Low to moderate	Moderate	Local, Regional

Volcano Hazard Location, Extent, and Magnitude

There are more than a dozen potentially active volcanoes in the Cascade Mountains (figure V1). Of the 20 total active volcanoes in the lower 48 states, five in Washington - Mount St. Helens, Mount Adams, Mount Rainier, Glacier Peak, and Mount Baker.

FIGURE V 2: CASCADE RANGE VOLCANOES

According to the USGS, four of Washington's volcanoes fall in the very high and high threat categories - Baker, Glacier Peak, Rainier, and St. Helens. The explosive behavior and lahar potential of these volcanoes can impact large populations and extensive development on the ground as well as heavily traveled air-traffic corridors.

The USGS's Volcano Hazards Program develops volcano hazard assessments to support informed hazard mitigation. Using knowledge of a volcano's past eruptions and an understanding of volcano activity at similar volcanoes, volcanologists can estimate long-term future activity. These estimates are combined with detailed topographic maps and digital elevation models to produce hazard zone maps and assessments. These assessments are updated as science improves.

Volcanic eruptions in the Cascades are infrequent but may have high consequences for those who live around them. The figure below shows the eruptive history of various volcanoes in the region based on the geologic record.

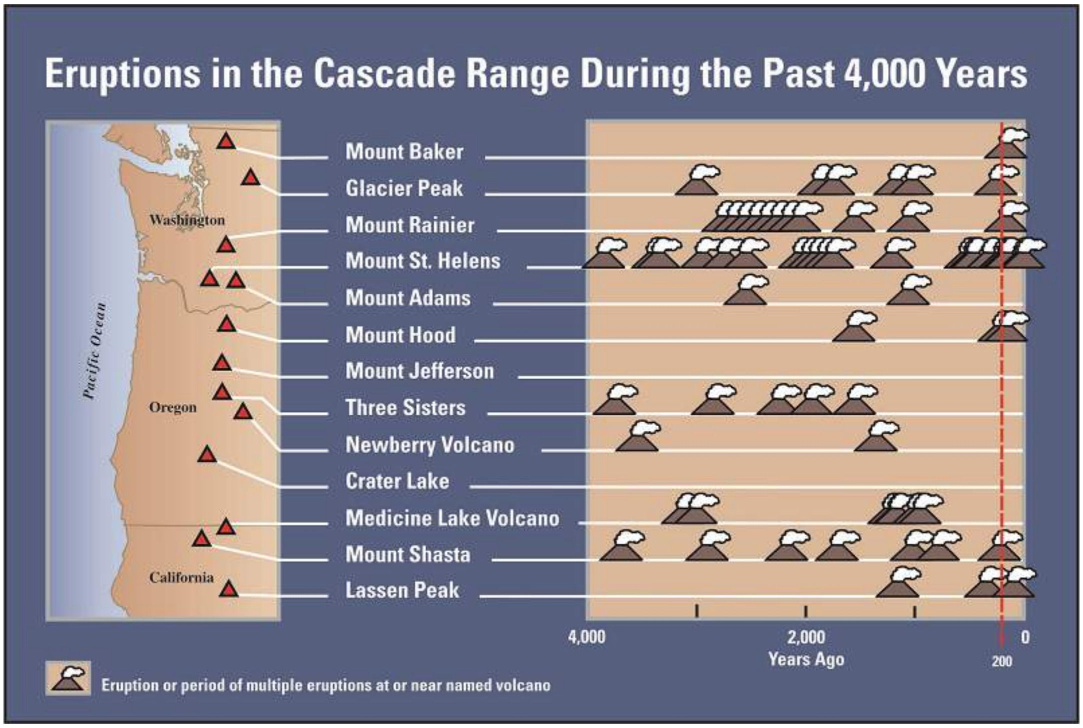


FIGURE V 3: ERUPTION HISTORY OF CASCADES (SOURCE: HTTPS://PNSN.ORG/VOLCANOES)

Volcanic hazard assessments are combined with qualitative information on the risks posed to people and property. "Overall threat ranking numerical values are assigned to the hazard and exposure factors at individual volcanoes. These factors are individually summed into a hazard score and an exposure score, which are then multiplied to generate the volcano's overall threat score. The resultant scores produce a relative ranking of U.S. volcanoes that can be grouped into five threat categories: Very High and High threat categories requiring the most robust monitoring coverage, a Moderate threat category requiring basic real-time monitoring coverage, and Low and Very Low threat categories requiring lesser degrees of monitoring" (Ewert et al., 2005).

Figure V 4: Volcano Risk Assessment Methodology (Source: USGS)

Mount Baker is one of the youngest Cascade volcanoes and erupts infrequently. Its last major eruptive period occurred about 6,600 years ago, where large portions of the flank repeatedly collapsed generating massive lahars. Lahar hazards are determined in part by mapping where lahars traveled in the past. Evidence of massive lahars is still abundant in many of the valleys that drain Mount Baker's glaciers (figure V5).

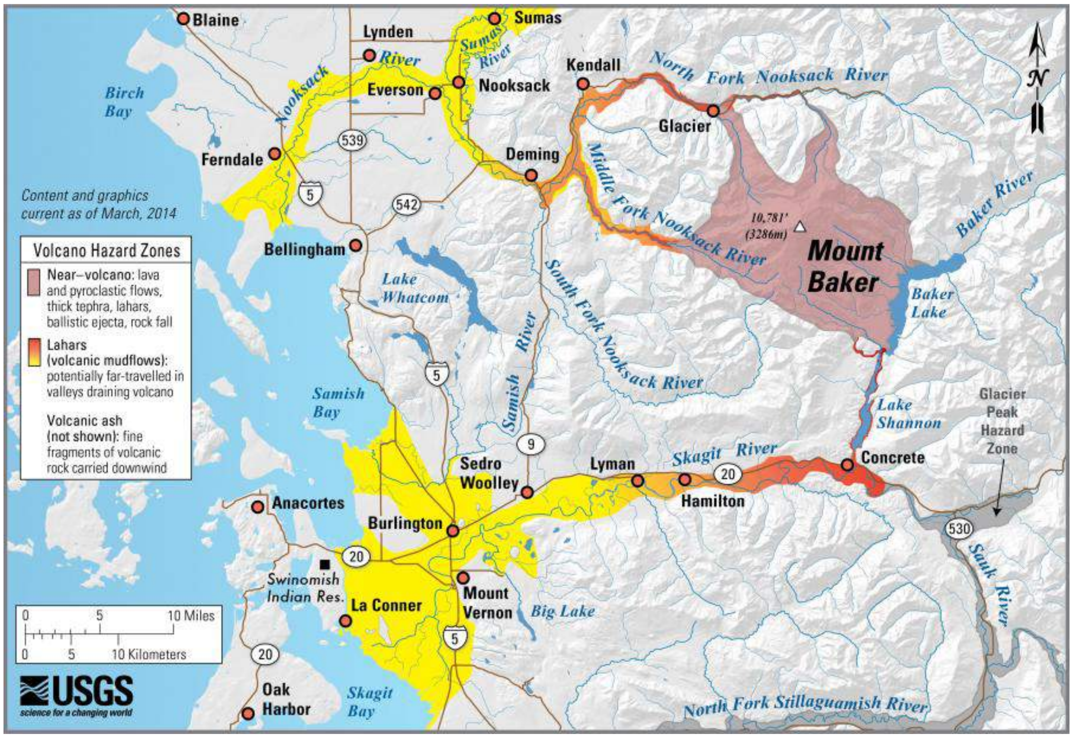


Figure V 5: Mt. Baker Volcano Hazard Zone

Glacier Peak is the least prominent, but one of the most explosive Cascade volcanoes. The volcano frequently and explosively produces dacitic lava domes, tephra, and far-reaching lahars. Geologic mapping has documented the extent of previous lahar runout in the Skagit and Stillaguamish River valleys. While Glacier Peak has shown no sign of eruption in the last few decades, the lahar deposits in the river valleys from past eruptions are a reminder of the hazard Glacier Peak poses to the communities living in the valleys adjacent to the volcano. Figure V6, shows simplified volcano hazard zones as identified by USGS. Many of the volcanic deposits have been either eroded or buried by rivers, glaciers, and human development.

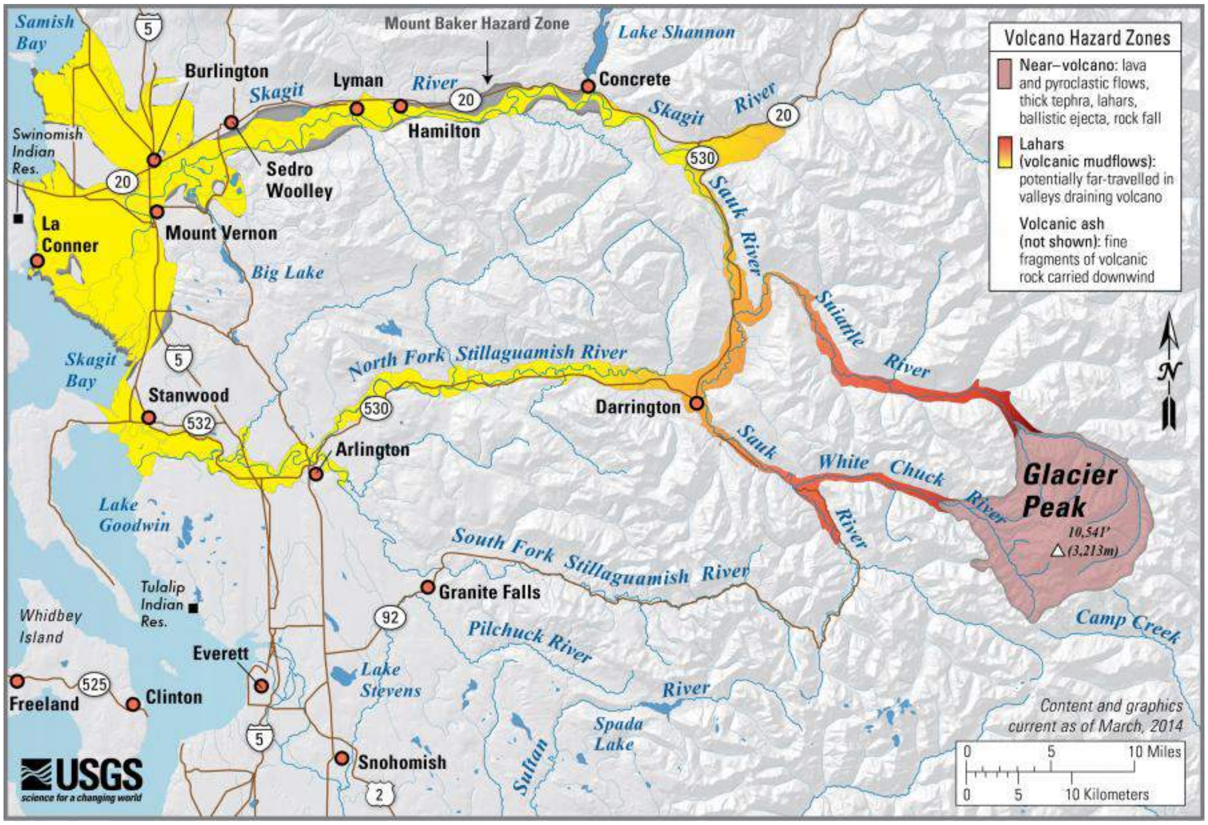


FIGURE V 6: GLACIER PEAK VOLCANO HAZARD ZONE

Mount Rainier started erupting 500,000 years ago with intermittent eruptions and mudflows thereafter. Mount Rainier still issues steam and gases from fumaroles near the summit crater. Heat from the fumaroles melts the snow and ice at the crater, as well as the summit icecap, forming caves beneath the ice. Figure V7, shows simplified volcano hazard zones as identified by USGS. Much of the volcanic deposits have been either eroded or buried by rivers, glaciers, and human development. Mt. Rainier a high-risk volcano because throughout its history, it has produced lahars that endanger populated areas and infrastructure. Due to the high lahar hazard to cities such as Orting and Puyallup, among others, two river valleys along Mt. Rainier have been equipped with a lahar detection system, and sirens to warn residents in the hazard zones of approaching danger.

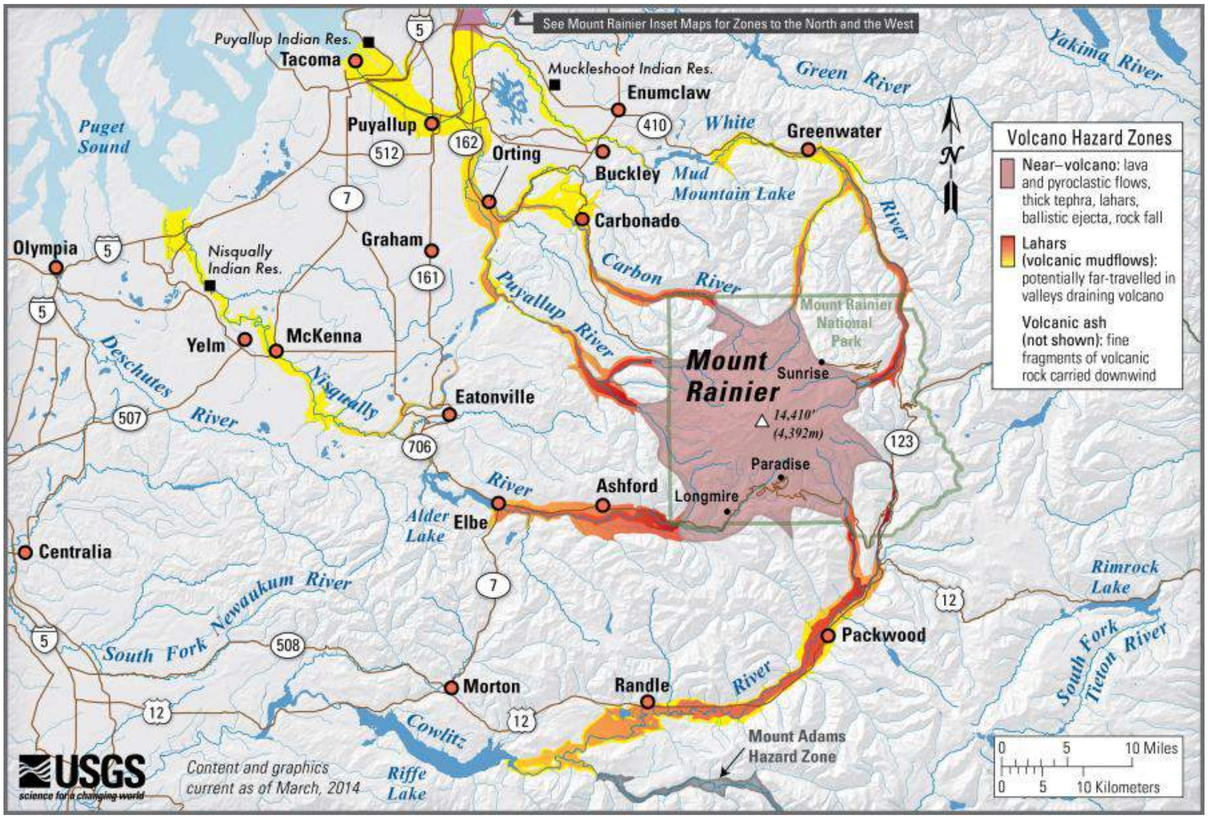


FIGURE V 7: MT. RAINIER VOLCANO HAZARD ZONE

Mount St. Helens produces dacitic to andesitic lava flows, pumice, and lahars. Like Glacier Peak, the composition of its magma makes it erupt more explosively than other Cascade volcanoes that erupt andesitic lava. Figure V8, shows simplified volcano hazard zones as identified by USGS. Some of these hazard zones needed to be updated following the May 1980 eruption of Mt. St. Helens, which erupted in an unexpected way, with a lateral blast and massive landslide, followed by devastating lahars.

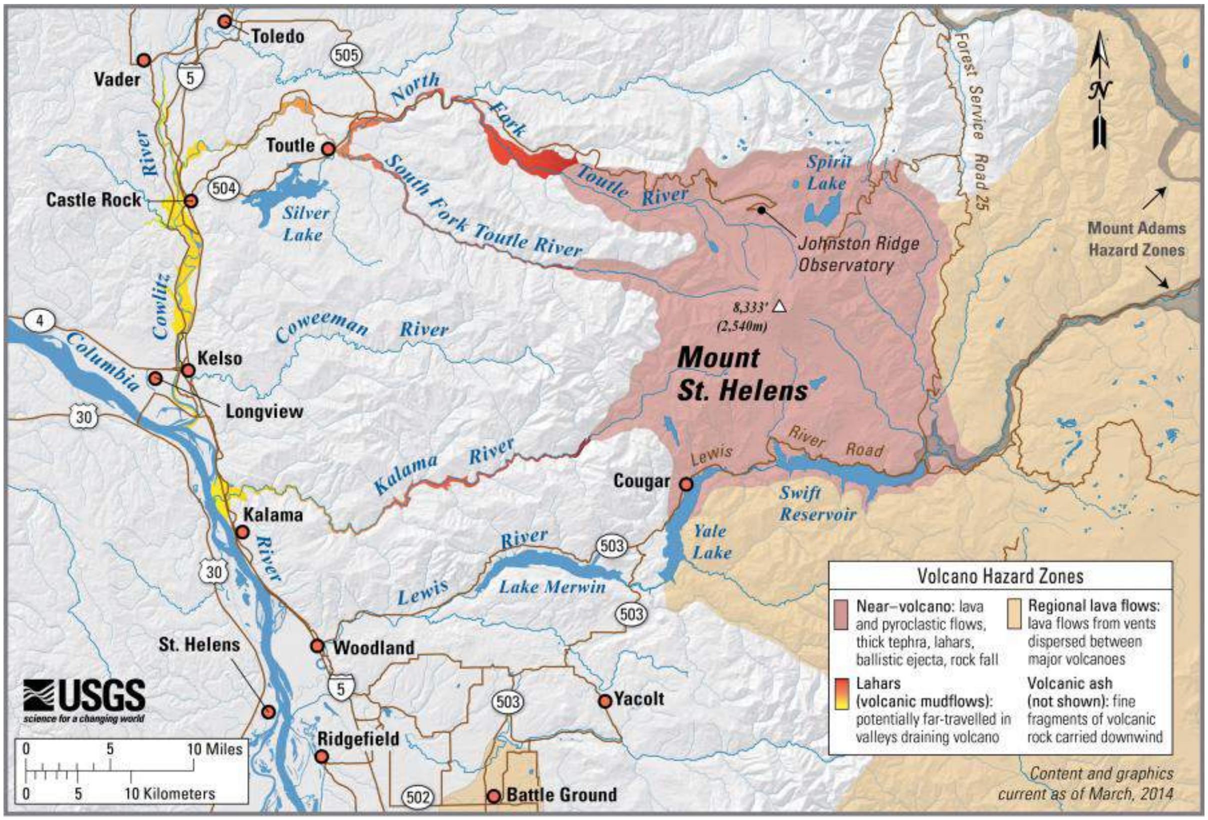


FIGURE V 8: MT. ST. HELENS VOLCANO HAZARD ZONE

Mount Adams is volumetrically the largest volcano in the Pacific Northwest. It is actually a cluster of volcanic vents that erupted andesitic lava from the vent cluster rather than a single vent. The Mount Adams system is one of the youngest in the Cascade Range and is situated further inland than most Cascade volcanoes. Figure V9, shows simplified volcano hazard zones as identified by USGS. Many of the volcanic deposits have been either eroded or buried by rivers, glaciers, and human development.

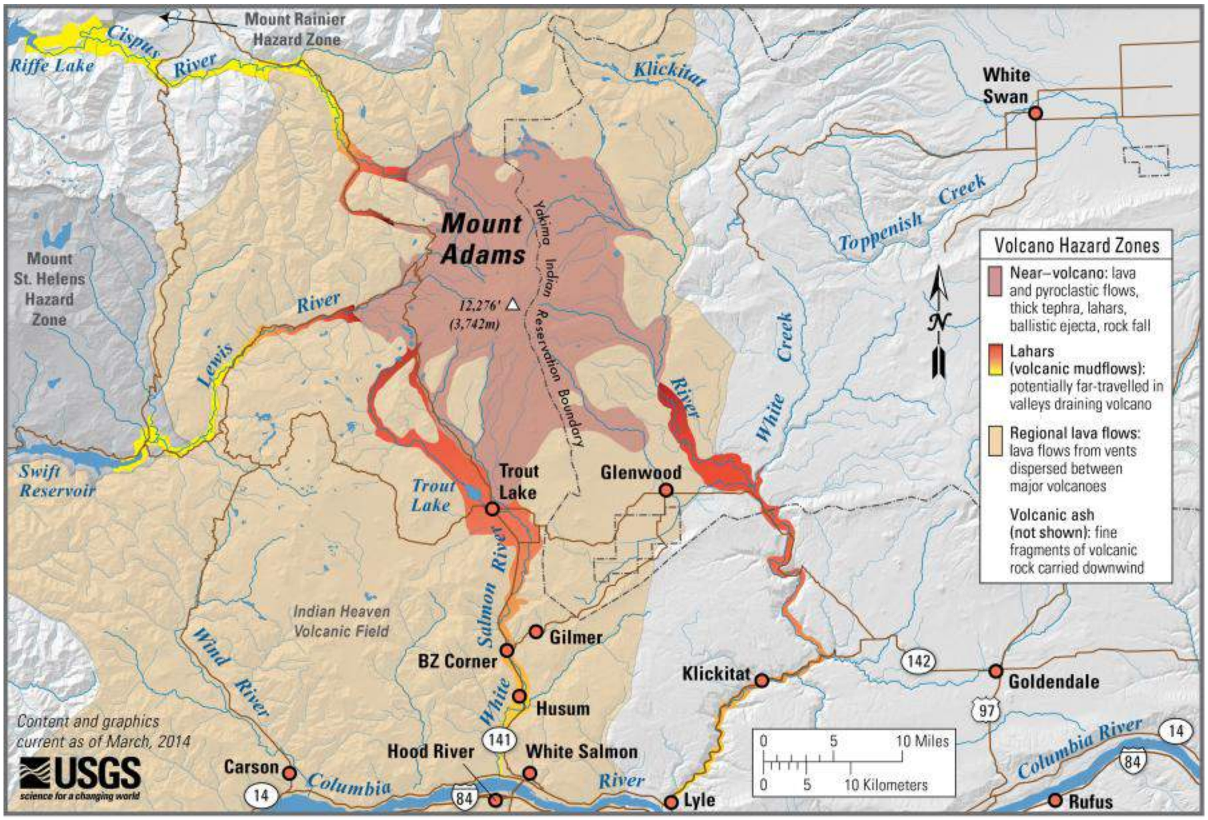


FIGURE V 9: MT. ADAMS VOLCANO HAZARD ZONE

The Volcanic Explosivity Index (VEI) is commonly used to describe the relative size of explosive volcanic eruptions (figure V10). Scores range from 0 to 8, with each number representing an increase in magnitude from the previous number by a factor of approximately ten. Several factors are taken into consideration to determine the magnitude, including the volume of erupted pyroclastic material (for example, ashfall, pyroclastic flows, and other ejecta), height of eruption column, duration in hours, and qualitative descriptions. VEI does not necessarily relate to the amount of sulfur dioxide injected to the atmosphere, which is critical in determining the climatic impacts of an eruption.

Large explosive eruptions occur much less frequently than small ones. Data from the Global Volcanism Program of the Smithsonian Institution indicates that “through 1994, the record of volcanic eruptions in the past 10,000 years . . . shows that there have been four eruptions with a VEI of 7, 39 of VEI 6, 84 of VEI 5, 278 of VEI 4, 868 of VEI 3, and 3,477 explosive eruptions of VEI 2”. Effects from the 1980 Mount St. Helens eruption can serve as one of the larger examples of potential volcanic events that could happen in the Northwest. This eruption measured at 5 on the VEI scale.

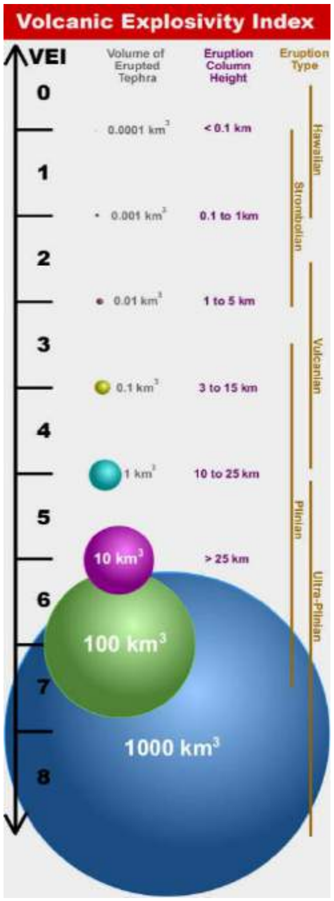


Figure V 10: Volcanic Explosivity Index

Past Occurrences and Future Likelihood

The only significant volcanic event in Washington during recent history was the eruption of Mount St. Helens in 1980. From March 16 to May 18 in 1980, a series of earthquakes, steam explosions, and small eruptions at the summit signaled a new eruptive phase of the volcano. By mid-April of 1980, a large bulge of new volcanic material had formed on the north flank of the mountain and moved outward at an average rate of ~5 feet per day.

On May 18th, the cataclysmic eruption was triggered by a magnitude 5.1 earthquake. The bulge collapsed in a series of three massive slide blocks. This bulge collapse generated a chain reaction, starting with the largest avalanche in recorded history (0.6 cubic miles of material, reaching speeds of 60 miles per hour). The removal of this material decreased the pressure holding back the magma and caused the sudden release of gas, large rocks, and smaller particles to move across the landscape and destroyed most vegetation at an astounding speed of 650 miles per hour. This initial blast caused major lahar flows, pyroclastic flows, and an ash eruption that formed an eruption column that grew to 12 miles high and 45 miles across. In addition to ash, pyroclastic flows and lahars traveled swiftly across the Pumice Plain and down the North Fork Toutle and Cowlitz Rivers, destroying houses and bridges along the way.

More recently in September 2004, earthquake swarms were observed along with minor explosions and lava dome growth in the summit crater. For the next 3+ years, lava continued to build in the crater and generated a lava dome that grew to a height of 1,500 feet. This activity continued steadily until late January of 2008. Figure V 11 provides eruptive history for Mount St. Helens.

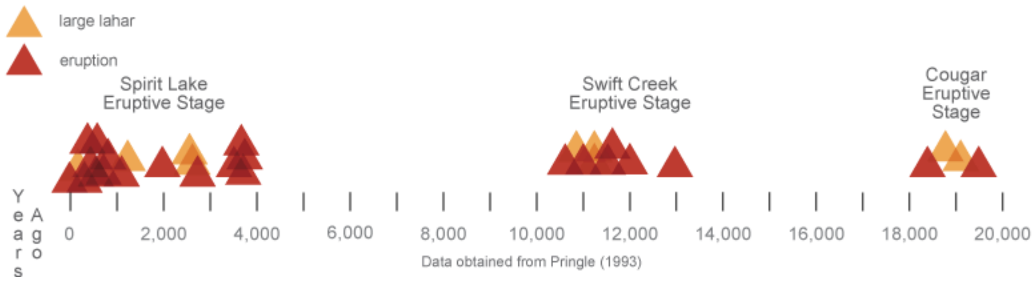


FIGURE V 11: ERUPTION HISTORY OF MT. ST. HELENS (SOURCE: DNR)

Mount Baker is one of the youngest Cascade volcanoes and erupts infrequently. Its last major eruptive period occurred about 6,600 years ago, where large portions of the flank repeatedly collapsed generating massive lahars. There are additional reports of eruptions and lahars from the 19th century, and as recently as 1975, fumarole activity and snow melt ramped up dramatically for several years. Figure V12 provides eruptive history for Mount Baker.

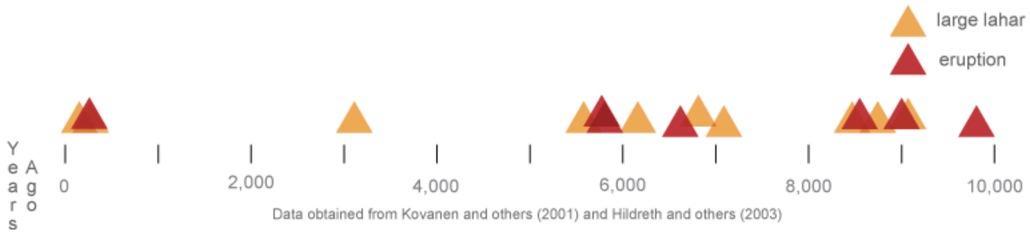


FIGURE V 12: ERUPTION HISTORY OF MT. BAKER (SOURCE: DNR)

Glacier Peak has erupted multiple times in the last 15,000 years. About 13,000 years ago, a series of large tephra eruptions occurred, accompanied by numerous lahars—one eruption was many times the size of the Mount St. Helens 1980 eruption. Within the last 5,000 years, the volcano produced frequent lava dome eruptions and subsequent dome collapse and lahars. The most recent eruption was only ~300 years ago. Figure V13 provides eruptive history for Glacier Peak.

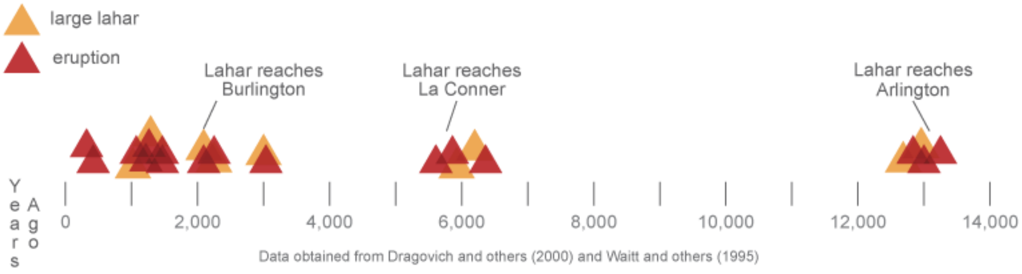
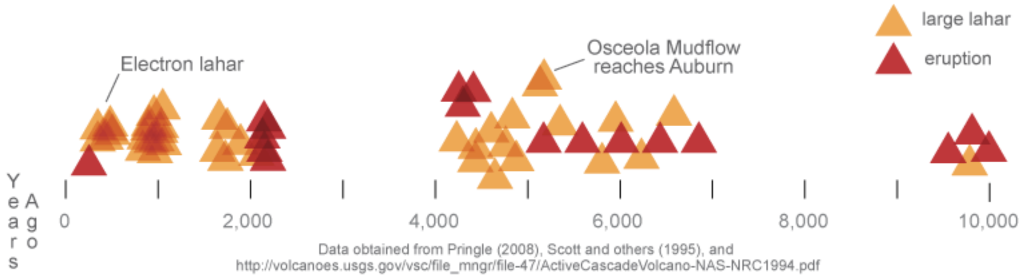


FIGURE V 13: ERUPTION HISTORY OF GLACIER PEAK (SOURCE: DNR)

Modern Mount Rainier started erupting only 500,000 years ago with intermittent eruptions and mudflows thereafter. About 5,600 years ago, a massive debris avalanche, called the Osceola

Mudflow, poured down from the summit of Mount Rainier, picking up sediment and anything else in its path as it traveled down the White River valley and into the Puget Sound. The mudflow filled valleys with up to ~400 feet of sediment and moved at speeds of 40 to 50 miles an hour. Following the Osceola Mudflow, many smaller volcanic eruptions and lahars occurred as the volcano continued to show signs of unrest.

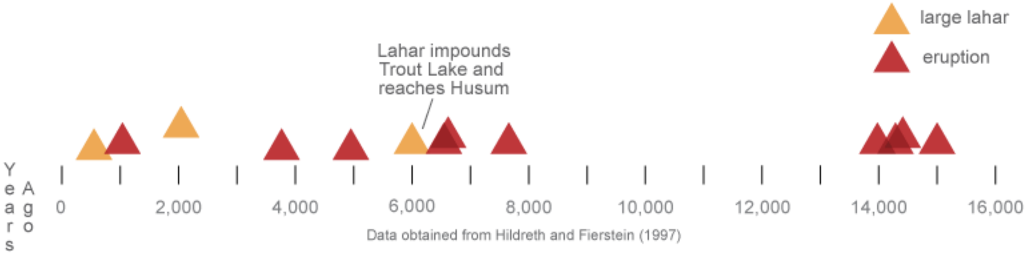
The most recent major mudflow, called the Electron Mudflow, began as a part of a crater collapse and traveled down the Puyallup River into Sumner in ~1502. It is estimated that Mount Rainier has generated about 60 of these large lahars in the last 10,000 years. Many of the communities, including Orting, Puyallup, and Auburn, between Mount Rainier and the Puget Sound are built on top of these deposits. Figure V14 provides eruptive history for Mount Rainier.



Data obtained from Pringle (2008), Scott and others (1995), and http://volcanoes.usgs.gov/vsc/file_mngr/file-47/ActiveCascadeVolcano-NAS-NRC1994.pdf

FIGURE V 14: ERUPTION HISTORY OF MT. RAINIER (SOURCE: DNR)

There have been no historical eruptions in the Mount Adams volcanic field. The volcanic center first erupted between 520,000 and 500,000 years ago and continued up to about 1,000 years ago. However, there were a series of debris avalanches and lahars between ~600 and 300 years ago. Hydrothermal alteration is present on the main cone as well as at numerous locations along the slope. Fumarole activity was reported at the summit from miners trying to extract sulfur from the crater in the 1930s, but later reconnaissance trips did not reveal any fumaroles—only the faint smell of sulfur. Figure V15 provides eruptive history for Mount Adams.



Data obtained from Hildreth and Fierstein (1997)

FIGURE V 15: ERUPTION HISTORY OF MT. ADAMS (SOURCE: DNR)

Cascade volcanoes are active volcanoes, will erupt again. While it's possible to have sufficient lead time for warning dissemination in case of an imminent eruption through appropriate monitoring, it is often difficult to predict future likelihood of volcanic events. According to the USGS, there is a 1-in-500 likelihood that portions of two counties will receive 10 centimeters (four inches) or more of volcanic ash from any Cascades volcano in any given year, and a 1-in-1,000 probability that parts or all of three or more counties will receive that quantity of ash. There is a 1-in-100 annual probability that small lahars or debris flows will impact river valleys below Mount Baker or Mount Rainier, and a less than 1-in-1000 annual probability that the large destructive lahars would flow down the slopes of Glacier Peak, Mount Adams, Mount Baker, and Mount Rainier. There is a much higher probability that significant areas of the state will experience smaller amounts of ash fall.

Relationship to Other Hazards

A volcanic event would have a large impact and could influence other hazards that pose a risk to the state. The location and severity of the eruption would dictate these impacts. The direct impacts could result from pyroclastic flows, tephra fall and lahar. Additionally, the movement of magma upward during an eruption could initiate seismic events. Pyroclastic flows can also lead to secondary hazards, especially flooding and lahars, by:

- Melting snow and ice, thereby sending a sudden torrent downstream.
- Damming or blocking streams in volcanic valleys, which may create lakes behind the blockage that eventually overtop and erode the blockage producing a rush of water and volcanic material downstream.
- Increasing the rate of stream runoff and erosion during rainstorms due to the creation of an easily eroded landscape with sparse vegetation.

Volcanic ash can have significant impact far beyond the eruption itself. Volcanic ash consists of tiny jagged pieces of rock and glass. Ash is hard, abrasive, mildly corrosive, conducts electricity when wet, and does not dissolve in water. Ash is spread over broad areas by wind. It can disrupt all transportation sectors (aviation, vehicles, roads, shipping channels), impact buildings - leading to roof collapse, transportation, power supply, causes health issues, and result in damages to numerous critical infrastructure facilities including electric sub-stations, and water treatment facilities. Volcanic Ash can be carried not only downwind, but downstream for miles by lahars, and subsequent erosion of their deposits. Transportation and deposition of this sediment can affect shipping channels for years to decades following an eruption.

Volcano Hazard Risk Assessment

Lahars and ash fall are the most important of the volcanic hazards that can cause concern for the communities at risk from volcanoes. Ash dispersion is primarily a function of the eruption intensity and the prevailing wind direction. As such, it is difficult to create ashfall hazard maps for volcanic eruptions. USGS provides a preliminary probabilistic tephra-hazard map for Pacific Northwest (Hoblitt et al. 2011), revised from Hoblitt et al. (1987) and Scott et al. (1995). Contours show the estimated probability of the accumulation of 10 centimeters or more of tephra from eruptions of the 16 major volcanic centers (black triangles) in the Cascade volcanic arc. It is evident that the contour pattern accentuates how Mount St. Helens' explosivity and high eruption frequency dominate the probability analysis. Therefore, this assessment is not suitable for risk analysis. Given the data limitations, ash hazard has not been considered in this vulnerability analysis.

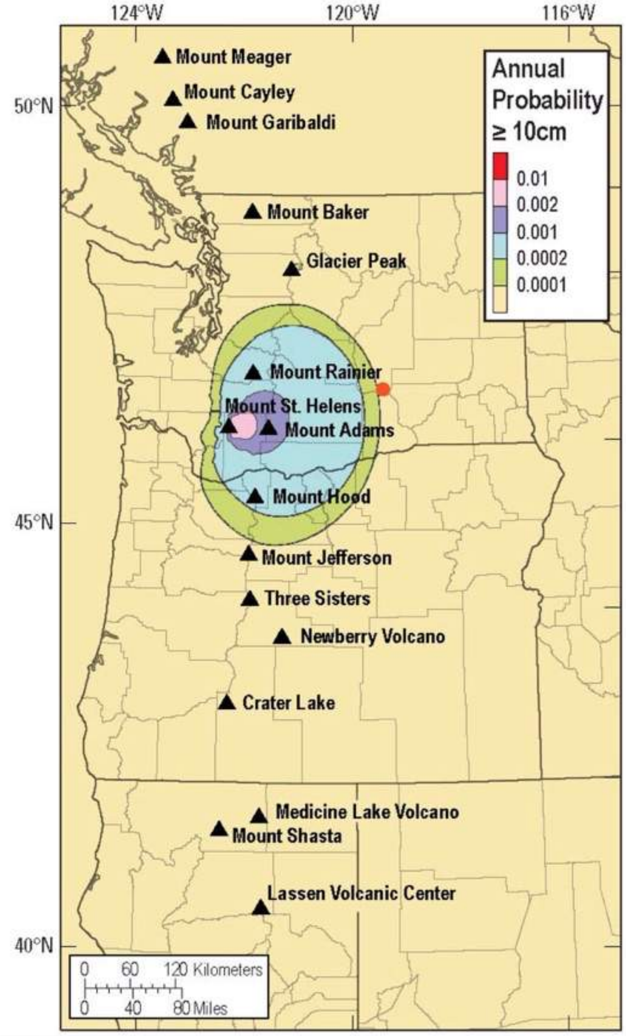


FIGURE V 16: PROBABILITY OF ASHFALL (SOURCE: CVO-USGS)

Therefore, this risk assessment is primarily based on the hazard risks posed by the five major volcanoes in Washington state. These include Mount Baker, Glacier Peak, Mount Rainier, Mount St. Helens, and Mount Adams. The Cascade Volcano Observatory has published detailed hazard zone maps for the lahar and regional lava flow hazards from key volcanoes in the state (discussed in the preceding sections). These hazard maps were used in this volcano risk assessment. The volcano hazard area is this identified as the area delineated as lahar hazard zone plus any identified regional lava flow zone in the USGS maps.

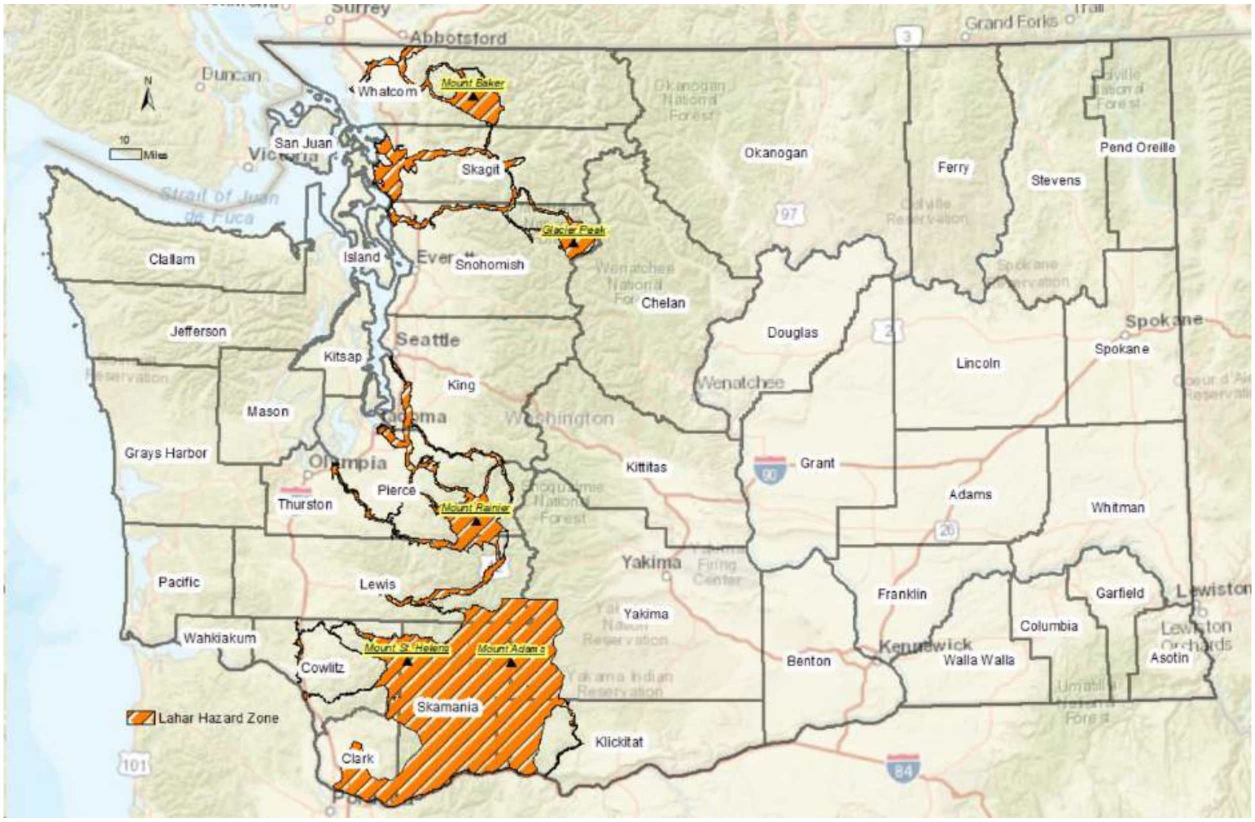


FIGURE V 17: VOLCANO LAHAR AND LAVA FLOW HAZARD ZONE (SOURCE: CVO-USGS)

While this assessment does provide a good overview of the regional exposure to volcano hazards, it is important to note that actual impacts will be dependent on the size of eruption and the prevalent wind direction (for ash hazard).

Area Exposure

The lahar and regional lava flow hazard zones were overlaid with the county map to estimate the area exposed to volcano hazards in each county. Not all counties are likely to be impacted by lahars from volcanic eruptions in the state. Lahars are likely to follow the regional topography and flow toward the Puget Sound via regional drainage channels. Only 13 counties in the state are likely to be directly impacted by volcanic lahars. About 6 percent of the land area in the state is exposed to volcano lahar hazard. Almost 90 percent of Skamania County falls within the lahar and lava flow hazard zone. Approximately 20 percent of Pierce County is exposed to volcanic lahar hazards. 34 percent of the Clark County is within the regional lava flow zone. Less than 5 percent of the King, Thurston, and Island Counties are also exposed to lahar hazards.

Percentage of County Land Area with Volcano Hazard Exposure	
County	In Hazard Zone
Adams	0.00
Asotin	0.00
Benton	0.00
Chelan	0.00
Clallam	0.00
Clark	33.73
Columbia	0.00
Cowlitz	12.67
Douglas	0.00
Ferry	0.00
Franklin	0.00
Garfield	0.00
Grant	0.00
Grays Harbor	0.00
Island	0.20
Jefferson	0.00
King	2.34
Kitsap	0.00
Kittitas	0.00
Klickitat	17.87
Lewis	10.28
Lincoln	0.00
Mason	0.00
Okanogan	0.00
Pacific	0.00
Pend Oreille	0.00
Pierce	19.07
San Juan	0.00
Skagit	12.22
Skamania	89.54
Snohomish	8.59
Spokane	0.00
Stevens	0.00
Thurston	2.15
Wahkiakum	0.00
Walla Walla	0.00
Whatcom	9.65
Whitman	0.00
Yakima	9.79
Washington State	5.71

Population Exposure

Population exposure was estimated by overlaying the volcano lahar and lava flow hazard layer over the 2011 developed areas derived from the land cover database. The 2017 estimated population for all census tracts was allocated to respective urban areas and the overlap with hazard exposure layer was estimated using spatial analysis in a geographic information system (GIS). Overall, 11.5 percent of the state population is in a volcano hazard zone. In Skamania County, almost all of the county's population is in the hazard zone. In Clark County 65 percent of the population, and in Skagit County 58 percent of the county population is in the hazard zone. In King County, almost 10 percent of the county population resides within the lahar hazard zone. Less than 5 percent of the county population is in the lahar hazard zone in Snohomish, Thurston, Island and Lewis counties.

In addition to the population within the direct path of the lahars, it is expected that significantly more people will likely be isolated by lahar flows. The numbers and extent of isolation will depend on the size of the lahar flow and its impact on local transportation and other infrastructure networks.

Population Exposure to Volcano Hazard

County	Total Population (2017 Estimates)	Percentage of Total State Population	Estimated County Population Exposed to Volcano Hazard (in % value)
Adams	19870	0.27	0.00
Asotin	22290	0.30	0.00
Benton	193500	2.65	0.00
Chelan	76830	1.05	0.00
Clallam	74240	1.02	0.00
Clark	471000	6.44	65.10
Columbia	4100	0.06	0.00
Cowlitz	105900	1.45	27.34
Douglas	41420	0.57	0.00
Ferry	7740	0.11	0.00
Franklin	90330	1.24	0.00
Garfield	2200	0.03	0.00
Grant	95630	1.31	0.00
Grays Harbor	72970	1.00	0.00
Island	82790	1.13	0.38
Jefferson	31360	0.43	0.00
King	2153700	29.46	9.80
Kitsap	264300	3.62	0.00
Kittitas	44730	0.61	0.00
Klickitat	21660	0.30	48.46
Lewis	77440	1.06	0.35
Lincoln	10700	0.15	0.00
Mason	63190	0.86	0.00

Okanogan	42110	0.58	0.00
Pend Oreille	13370	0.18	0.00
San Juan	16510	0.23	0.00
Skamania	11690	0.16	97.91
Spokane	499800	6.84	0.00
Thurston	276900	3.79	2.03
Walla Walla	61400	0.84	0.00
Whitman	48640	0.67	0.00
Washington State	7310300	100.00	11.50

Vulnerable Population Exposure

The social vulnerability index was created for each census tract using American Community Survey (ACS) 2011-2016 5-year data. Social vulnerability data was first overlaid with developed areas extracted from the 2011 land cover database. Tract-level social vulnerability estimates were assigned to respective developed areas in each of the tracts. This data was then overlaid with volcano hazard layer to identify socially vulnerable developed areas that overlap with volcano hazard areas. Overall less than 2 percent of the State population is vulnerable and resides in hazard zones. In Clark, Skagit, and King Counties, about 4 percent of the county population is ranked medium or higher on social vulnerability index and resides in the volcano hazard zone.

Vulnerable Population Exposure to Volcano Hazard

County	Population (2017 Estimates)	Hazard Exposure	
		Estimated Population	As % of County Population
Adams	19870	0	0.00
Asotin	22290	0	0.00
Benton	193500	0	0.00
Chelan	76830	0	0.00
Clallam	74240	0	0.00
Clark	471000	15345	3.26
Columbia	4100	0	0.00

Vulnerable Population Exposure to Volcano Hazard

County	Population (2017 Estimates)	Hazard Exposure	
		Estimated Population	As % of County Population
Cowlitz	105900	763	0.72
Douglas	41420	0	0.00
Ferry	7740	0	0.00
Franklin	90330	0	0.00
Garfield	2200	0	0.00
Grant	95630	0	0.00
Grays Harbor	72970	0	0.00
Island	82790	0	0.00
Jefferson	31360	0	0.00
King	2153700	80357	3.73
Kitsap	264300	0	0.00
Kittitas	44730	0	0.00
Klickitat	21660	0	0.00
Lewis	77440	0	0.00
Lincoln	10700	0	0.00
Mason	63190	0	0.00
Okanogan	42110	0	0.00
Pacific	21250	0	0.00
Pend Oreille	13370	0	0.00
Pierce	859400	13791	1.60
San Juan	16510	0	0.00
Skagit	124100	4051	3.26
Skamania	11690	0	0.00
Snohomish	789400	0	0.00
Spokane	499800	0	0.00
Stevens	44510	0	0.00
Thurston	276900	0	0.00
Wahkiakum	4030	0	0.00
Walla Walla	61400	0	0.00
Whatcom	216300	0	0.00
Whitman	48640	0	0.00
Yakima	253000	0	0.00
Washington State	7310300	92851	1.27

Built Environment Exposure

The built environment exposure is calculated using general building stock data (2014) provided by FEMA that contains the building values for all structures in census tracts. General building stock values used in this analysis are the total structure value of all buildings (except agricultural) in each census tract in 2014 dollars. Building values for all occupancy types were summed for each census tract using only structure values (not content values) and assigned to the developed areas within each tract. These maps were then overlaid on the hazard layer to estimate the general building stock value within the hazard exposure areas. Individual tract level estimates were aggregated to create the county level estimates. Overall, about 12 percent of the state general building stock is in a lahar hazard zone. However, in Skamania County all of the county general building stock is located within the lahar hazard zone. In Clark County 65 percent of the general building stock is in the hazard zone, though none is exposed directly to lahars. In Skagit and Klickitat Counties, approximately 50 percent of the general building stock is in a lahar hazard zone.

Built Environment Exposure to Volcano

County	Total Value of General Building Stock (2014)	Exposed to Volcano Hazards	
		Total Value of General Building Stock (2014)	Percent of Total County General Building Stock (2014)
Adams	$253,615	$0	0.00
Asotin	$1,061,235	$0	0.00
Benton	$6,529,565	$0	0.00
Chelan	$1,573,417	$0	0.00
Clallam	$2,427,219	$0	0.00
Clark	$32,074,170	$20,880,026	65.10
Columbia	$533	$0	0.00
Cowlitz	$4,992,730	$1,364,864	27.34
Douglas	$1,211,949	$0	0.00
Ferry	$1,521	$0	0.00
Franklin	$1,867,499	$0	0.00
Garfield	$437	$0	0.00
Grant	$583,022	$0	0.00
Grays Harbor	$1,162,104	$0	0.00
Island	$2,895,464	$11,084	0.38
Jefferson	$1,137,144	$0	0.00
King	$362,698,022	$35,530,737	9.80
Kitsap	$17,267,166	$0	0.00
Kittitas	$530,126	$0	0.00
Klickitat	$4,479	$2,170	48.46
Lewis	$1,402,914	$4,912	0.35
Lincoln	$87,198	$0	0.00
Mason	$608,531	$0	0.00
Okanogan	$59,252	$0	0.00
Pacific	$125,715	$0	0.00
Pend Oreille	$8,310	$0	0.00
Pierce	$62,547,883	$9,247,783	14.79
San Juan	$225,856	$0	0.00
Skagit	$5,389,339	$3,104,363	57.60
Skamania	$17,391	$17,028	97.91
Snohomish	$52,406,666	$1,925,710	3.67
Spokane	$31,281,088	$0	0.00
Stevens	$325,218	$0	0.00
Thurston	$9,798,392	$198,949	2.03
Wahkiakum	$1,649	$0	0.00

Walla Walla	$3,061,065	$0	0.00
Whitman	$1,385,430	$0	0.00
Washington State	$630,231,344	$72,457,194	11.50

Critical Infrastructure Exposure

Critical infrastructure facilities that lie within the hazard exposure areas will be directly impacted. While the nature and degree of impact will largely depend on the size of the volcano eruption, the resulting lahar and the physical details of the facility, spatial overlay analysis can enable prioritization of site specific hazard mitigation studies. Location of 12 critical infrastructure facility types including airports (23), communication towers (16097), dams (268), education facilities (5331), electric substations (1392), hospitals (147), power plants (146), public transit stations (60), railroad bridges (1619), railway stations (317), urgent care facilities (113), and weather radar stations (2), were derived from the Homeland Security Foundation Level Database (HIFLD). This data was overlaid with the volcano hazard zone to identify facilities exposed to volcano lahar or lava flow hazard. This analysis refers to point data and not critical infrastructure represented by networks such as roads and rail corridors. Lahar flows will impact transportation corridors and other infrastructure networks. However, due to data limitations this analysis of infrastructure networks has not been considered in this analysis. Less than 10 percent of critical infrastructure facilities in the state are in hazard zone. In Skamania County 97 percent of the critical infrastructure facilities are in hazard zone. Other counties with significant number of critical infrastructure facilities in the hazard zone include Clark County (40 percent), Skagit County (27 percent), Pierce County (24 percent), Klickitat County (20 percent), Whatcom (11 percent), and King County (10 percent).

Critical Infrastructure Exposure			
County	**Number of Critical Infrastructure Facilities**	**In areas with hazard exposure**	
		Number of Critical Infrastructure Facilities	**Percent of Critical Infrastructure Facilities**
Adams	206	0	0.00
Asotin	81	0	0.00
Benton	664	0	0.00
Chelan	507	0	0.00
Clallam	273	0	0.00
Clark	490	197	40.20
Columbia	88	0	0.00
Cowlitz	474	39	8.23
Douglas	290	0	0.00

Critical Infrastructure Exposure

County	Number of Critical Infrastructure Facilities	In areas with hazard exposure	
		Number of Critical Infrastructure Facilities	Percent of Critical Infrastructure Facilities
Ferry	83	0	0.00
Franklin	270	0	0.00
Garfield	89	0	0.00
Grant	501	0	0.00
Grays Harbor	377	0	0.00
Island	104	0	0.00
Jefferson	197	0	0.00
King	2761	266	9.63
Kitsap	451	0	0.00
Kittitas	303	0	0.00
Klickitat	322	61	18.94
Lewis	374	12	3.21
Lincoln	237	0	0.00
Mason	152	0	0.00
Okanogan	359	0	0.00
Pacific	152	0	0.00
Pend Oreille	69	0	0.00
Pierce	1130	268	23.72
San Juan	98	0	0.00
Skagit	474	130	27.43
Skamania	145	140	96.55
Snohomish	787	39	4.96
Spokane	933	0	0.00
Stevens	211	0	0.00
Thurston	462	6	1.30
Wahkiakum	17	0	0.00
Walla Walla	273	0	0.00
Whatcom	613	66	10.77
Whitman	409	0	0.00
Yakima	601	0	0.00
Washington State	16027	1224	7.64

State Operations and Facilities Exposure

The list of state owned (9415) and leased facilities (1039) was obtained from 2017 Facilities Inventory System Report produced by Office of Financial Management (detailed list included in Appendix). These facilities were geo-located based on the addresses provided in the facilities inventory report and then overlaid with the hazard layer.

It is estimated that less than 2 percent of the state-owned facilities and about 7 percent state-leased facilities are in hazard zones. The highest number of state-owned facilities in the hazard zone is in King County (60) followed by Pierce County which has 47 state-owned facilities located in the hazard zones. However, they constitute approximately only 6 percent of the total state-owned facilities in each of these counties. In Skagit County, 67 percent of the state-leased facilities are in a hazard zone.

State Owned and Leased Facilities Exposure

County	State Owned Facilities	State Leased Facilities	In areas Exposed to Hazards			
			State Owned Facilities	Percent of State Owned Facilities	State Leased Facilities	Percent of State Leased Facilities
Adams	64	1	0	0.00	0	0.00
Asotin	90	6	0	0.00	0	0.00
Benton	159	30	0	0.00	0	0.00
Chelan	192	22	0	0.00	0	0.00
Clallam	183	12	0	0.00	0	0.00
Clark	229	23	17	7.42	15	65.22
Columbia	75	1	0	0.00	0	0.00
Cowlitz	128	18	4	3.13	1	5.56
Douglas	42	10	0	0.00	0	0.00
Ferry	32	3	0	0.00	0	0.00
Franklin	160	9	0	0.00	0	0.00
Garfield	21	0	0	0.00	0	0.00
Grant	252	15	0	0.00	0	0.00
Grays Harbor	224	13	0	0.00	0	0.00
Island	269	6	0	0.00	0	0.00
Jefferson	394	5	0	0.00	0	0.00
King	1120	226	60	5.36	35	15.49
Kitsap	269	15	0	0.00	0	0.00
Kittitas	348	11	0	0.00	0	0.00
Klickitat	110	10	8	7.27	6	60.00
Lewis	163	13	0	0.00	0	0.00
Lincoln	58	0	0	0.00	0	0.00
Mason	244	7	0	0.00	0	0.00
Okanogan	179	10	0	0.00	0	0.00
Pacific	233	6	0	0.00	0	0.00
Pend Oreille	18	5	0	0.00	0	0.00
Pierce	865	54	47	5.43	6	11.11
San Juan	282	5	0	0.00	0	0.00
Skagit	286	15	22	7.69	10	66.67
Skamania	64	2	7	10.94	2	100.00
Snohomish	270	71	0	0.00	0	0.00
Spokane	571	121	0	0.00	0	0.00
Stevens	65	7	0	0.00	0	0.00
Thurston	431	166	0	0.00	0	0.00
Wahkiakum	22	0	0	0.00	0	0.00
Walla Walla	159	11	0	0.00	0	0.00

State Owned and Leased Facilities Exposure						
County	State Owned Facilities	State Leased Facilities	In areas Exposed to Hazards			
			State Owned Facilities	Percent of State Owned Facilities	State Leased Facilities	Percent of State Leased Facilities
Whitman	566	9	0	0.00	0	0.00
Washington State	9415	1031	165	1.75	75	7.27

First Responder Facilities Exposure

Locations of fire stations, law enforcement buildings, and emergency medical stations in the State were identified from the Homeland Security Foundation Level Database (HIFLD). Using ESRI ArcMap geocoding services 1,268 fire stations, 332 law enforcement agencies, and 1,162 EMS stations (including those co-located with fire stations) were located on the state map. It is estimated that 7 percent of the fire stations, 10 percent of the law enforcement buildings, and 8 percent of the EMS facilities are in a hazard zone. Clark and Pierce counties have the most fire stations (18), located in hazard zone. King and Clark counties have the most law enforcement buildings (seven each) in hazard zones. Clark and Pierce Counties each have 18 EMS facilities in lahar hazard zone.

First Responder Facilities Exposure to Volcano Hazards									
County	Fire Station			Law Enforcement			EMS		
	Total Number of Facilities	In areas of Exposure		Total Number of Facilities	In areas of Lahar Exposure		Total Number of Facilities	In areas of Exposure	
		Number of facilities	Percent Facilities		Number of facilities	Percent Facilities		Number of facilities	Percent Facilities
Adams	11	0	0.00	4	0	0.00	5	0	0.00
Asotin	3	0	0.00	4	0	0.00	2	0	0.00
Benton	29	0	0.00	7	0	0.00	27	0	0.00
Chelan	30	0	0.00	3	0	0.00	21	0	0.00
Clallam	22	0	0.00	5	0	0.00	24	0	0.00
Clark	40	18	45.00	13	7	53.85	40	18	45.00
Columbia	3	0	0.00	1	0	0.00	2	0	0.00
Cowlitz	25	3	12.00	8	2	25.00	17	2	11.76
Douglas	12	0	0.00	3	0	0.00	8	0	0.00
Ferry	12	0	0.00	3	0	0.00	5	0	0.00
Franklin	20	0	0.00	7	0	0.00	15	0	0.00
Garfield	2	0	0.00	1	0	0.00	1	0	0.00
Grant	50	0	0.00	15	0	0.00	28	0	0.00
Grays Harbor	32	0	0.00	9	0	0.00	20	0	0.00
Island	10	0	0.00	4	0	0.00	9	0	0.00
Jefferson	12	0	0.00	4	0	0.00	13	0	0.00
King	159	12	7.55	60	7	11.67	161	16	9.94
Kitsap	47	0	0.00	6	0	0.00	49	0	0.00

First Responder Facilities Exposure to Volcano Hazards

County	Fire Station			Law Enforcement			EMS		
	Total Number of Facilities	In areas of Exposure		Total Number of Facilities	In areas of Lahar Exposure		Total Number of Facilities	In areas of Exposure	
		Number of facilities	Percent Facilities		Number of facilities	Percent Facilities		Number of facilities	Percent Facilities
Klickitat	36	8	22.22	3	1	33.33	25	5	20.00
Lincoln	10	0	0.00	4	0	0.00	9	0	0.00
Okanogan	27	0	0.00	7	0	0.00	17	0	0.00
Pend Oreille	18	0	0.00	1	0	0.00	16	0	0.00
San Juan	4	0	0.00	1	0	0.00	5	0	0.00
Skamania	3	3	100.00	2	2	100.00	3	3	100.00
Spokane	52	0	0.00	10	0	0.00	50	0	0.00
Thurston	47	0	0.00	17	0	0.00	55	0	0.00
Walla Walla	21	0	0.00	3	0	0.00	20	0	0.00
Whitman	24	0	0.00	8	0	0.00	22	0	0.00
Grand Total	1268	91	7.18	332	32	9.64	1162	89	7.66

Washington State Risk Index for Volcano Hazards (WaSRI-V)

The volcano risk index (WaSRI-V) for each county is estimated as the average of the standardized rank of hazard exposure assessment for county area, population, vulnerable populations, built environment, critical infrastructure facilities, state facilities and first responder facilities. The individual exposure assessment values were categorized into five classes (1: Low, 2: Medium-Low, 3: Medium, 4: Medium-High, and 5: High) using z-score transformation (standard deviations from the mean).

Classification Schema for Standardized Exposure Assessment Values

Standard Deviation	Classification Rank
>1	High (5)
0.50 to 1.0	Medium-High (4)

0.5 to -0.5	Medium (3)
-0.5 to -1	Medium-Low (2)
< -1.0	Low (1)

The volcano risk index (WaSRI-V) is the mean of these individual exposure rankings. While similar assessments were also done for economic consequences (described in the next sections), these specific rankings were not included in the estimation of the risk index. Economic consequence rankings were not included because of data quality limitations. Economic consequences estimates are based on overall county data. Including them in the index is likely to result in biased estimation of hazard risk. Similar data limitations exist with respect to environmental impact assessment. The data for environmental resources is limited to the land cover categories provided in the national land cover dataset. Each natural hazard is associated with specific effects on the natural environment and therefore adoption of a common evaluation approach across all hazard types for environmental impacts is not appropriate. Therefore, for volcano hazard, no quantitative assessment of environmental impacts was undertaken. However, general possible impacts on the environment have been discussed briefly in the appropriate section.

Only 13 counties in the state are likely to be directly impacted by volcanic lahars. Among these Skamania, Clark, and Skagit are at the highest risk from volcanic lahars, followed by Klickitat, Cowlitz, and Pierce counties. King and Whatcom counties are at medium risk from volcanic lahars. Although Clark County is not exposed to lahars, much of the county, including its most populous areas, are within the regional lava flow hazard area.

Volcano Risk Index (WaSRI V) and Constituent Exposure Ranks for Each County

County	Area	Population	Vulnerable Population	Built Environment	Critical Infrastructure	State Facilities	First Responder Facilities	Volcano Risk Index (WaSRI V)
Adams								
Asotin								
Benton								
Chelan								
Clallam								
Clark	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH
Columbia								
Cowlitz	MEDIUM-HIGH	MEDIUM-HIGH	MEDIUM-HIGH	MEDIUM-HIGH	MEDIUM	MEDIUM-LOW	MEDIUM-HIGH	MEDIUM-HIGH
Douglas								
Ferry								

Franklin								
Garfield								
Grant								
Grays Harbor								
Island	LOW	MEDIUM-LOW	MEDIUM-LOW	MEDIUM-LOW	LOW	MEDIUM-HIGH	LOW	**MEDIUM-LOW**
Jefferson								
King	MEDIUM-LOW	MEDIUM	HIGH	MEDIUM	MEDIUM	MEDIUM-HIGH	MEDIUM	MEDIUM
Kitsap								
Kittitas								
Klickitat	MEDIUM-HIGH	MEDIUM-HIGH	MEDIUM-LOW	MEDIUM-HIGH	MEDIUM-HIGH	HIGH	MEDIUM-HIGH	MEDIUM-HIGH
Lewis	MEDIUM	LOW	MEDIUM-LOW	LOW	MEDIUM-LOW	MEDIUM-LOW	MEDIUM	MEDIUM-LOW
Lincoln								
Mason								
Okanogan								
Pacific								
Pend Oreille								
Pierce	HIGH	MEDIUM	MEDIUM-HIGH	MEDIUM	MEDIUM-HIGH	MEDIUM	MEDIUM-HIGH	MEDIUM-HIGH
San Juan								
Skagit	MEDIUM-HIGH	HIGH	HIGH	HIGH	HIGH	MEDIUM-HIGH	HIGH	HIGH
Skamania	HIGH	HIGH	MEDIUM-LOW	HIGH	HIGH	HIGH	HIGH	HIGH
Snohomish	MEDIUM-LOW	MEDIUM-LOW	MEDIUM-LOW	MEDIUM-LOW	MEDIUM-LOW	LOW	MEDIUM-LOW	MEDIUM-LOW
Spokane								
Stevens								
Thurston	LOW	MEDIUM-LOW	MEDIUM-LOW	MEDIUM-LOW	MEDIUM-LOW	LOW	LOW	LOW
Wahkiakum								

Walla Walla								
Whatcom	MEDIUM	MEDIUM-HIGH	MEDIUM-LOW	MEDIUM-HIGH	MEDIUM-HIGH	MEDIUM	MEDIUM	MEDIUM
Whitman								
Yakima	MEDIUM	LOW	MEDIUM-LOW	LOW	LOW	MEDIUM-LOW	LOW	LOW

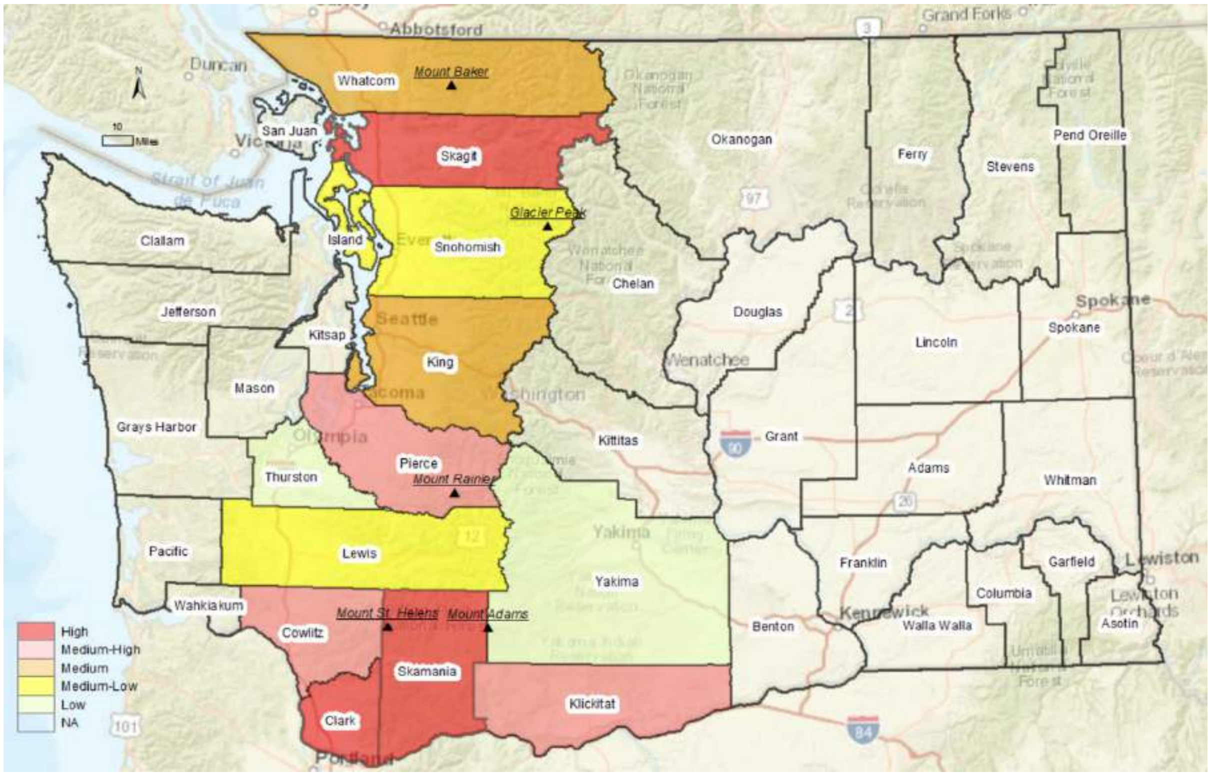


FIGURE V18: VOLCANO RISK INDEX (WASRI-V)

Economic Consequences

The economic activity data was derived from National Association of Counties. This dataset provides the county-level estimates of Gross Domestic Product (GDP) for 2016. The counties ranked medium or higher on the volcano risk index account for 18 percent of the state GDP. King County, by far the highest contributor to the state GDP is ranked medium for volcanic hazard risks. The next two top contributors to state GDP, Pierce and Snohomish counties are ranked medium-high and medium-low on the volcano risk index. However, it is expected that volcanic events are also likely to cause significant impact on the local and regional vehicular and air travel patterns. These economic consequences are not included in this analysis.

Volcano Risk (WaSRI V) and County GDP 2016		
County	Drought Risk Index (WaSRI D)	GDP 2016 (in Mil.)
Adams		$746.07

Volcano Risk (WaSRI V) and County GDP 2016

County	Drought Risk Index (WaSRI D)	GDP 2016 (in Mil.)
Asotin		$618.43
Benton		$10,627.85
Chelan		$4,363.01
Clallam		$2,573.06
Clark	HIGH	$18,682.64
Columbia		$144.20
Cowlitz	MEDIUM-HIGH	$4,474.88
Douglas		$1,037.39
Ferry		$198.13
Franklin		$3,356.16
Garfield		$97.44
Grant		$3,803.65
Grays Harbor		$2,237.44
Island	MEDIUM-LOW	$2,796.80
Jefferson		$867.23
King	MEDIUM	$230,344.61
Kitsap		$12,082.18
Kittitas		$1,566.21
Klickitat	MEDIUM-HIGH	$1,004.05
Lewis	MEDIUM-LOW	$2,573.06
Lincoln		$347.25
Mason		$1,566.21
Okanogan		$1,678.08
Pacific		$637.45
Pend Oreille		$354.63
Pierce	MEDIUM-HIGH	$41,280.80
San Juan		$602.88
Skagit	HIGH	$5,705.48
Skamania	HIGH	$218.04
Snohomish	MEDIUM-LOW	$39,378.97
Spokane		$24,723.73
Stevens		$1,111.56
Thurston	LOW	$12,865.29
Wahkiakum		$93.41
Walla Walla		$2,908.67
Whatcom	MEDIUM	$10,068.49
Whitman		$2,237.44
Yakima	LOW	$10,404.10

Risk to Environment

Volcanic eruptions will significantly impact the local environmental resources. Lahars and pyroclastic flows devastate vegetation in its path. Ash deposits are also likely to negatively impact the local ecological diversity.

Ash fall can stress insect populations, bury grasses, and reduce initial soil productivity due to reduced photosynthesis and reduced permeability (Cook et al. 1981). It can also block water courses, and initially at least, stress existing riparian environments. The abrasive nature of the ash can stress both plans and animals. On the positive side, harmful insects can also be stressed resulting in reduced populations and ash can add value to some soils over time (Robock 2000). There may be a beneficial effect from the introduction of new nutrients being added to the soil and there could be an additional benefit through the suppression of germinating weed seeds

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Wildfire Risk Summary

<table>
<tr><th>Washington State Risk Index for Wildfires (WaSRI-WF)</th><th>MEDIUM</th></tr>
<tr><td>LIKELIHOOD</td><td>HIGH</td></tr>
<tr><td colspan="2">Washington experiences a number of wildfires annually. Most of these are smaller wildfires, but a few do result in widespread impacts. Our changing climate is increasing the risk of more intensive wildland fires.</td></tr>
<tr><td>HAZARD AREA</td><td>Medium</td></tr>
<tr><td colspan="2">22%of the State is exposed to medium or higher wildfire hazard. Climate change is increasing the land exposed.</td></tr>
<tr><td>POPULATION</td><td>LOW</td></tr>
<tr><td colspan="2">8% of the State population is exposed to medium or higher landslide hazard.</td></tr>
<tr><td>VULNERABLE POPULATION</td><td>LOW</td></tr>
<tr><td colspan="2">Less than 2% of the State population resides in areas ranked medium or higher on social vulnerability and is also exposed to medium or higher wildfires.
Populations vulnerable to respiratory issues experience impacts on a far wider scale due to the spread of smoke.</td></tr>
<tr><td>BUILT ENVIRONMENT</td><td>MEDIUM</td></tr>
<tr><td colspan="2">21.5% of the general building stock of the State is located in areas exposed to landslides</td></tr>
<tr><td>CRITICAL INFRASTRUCTURE</td><td>MEDIUM-LOW</td></tr>
<tr><td colspan="2">13% of the facilities are located in areas exposed to medium or higher landslide hazard.</td></tr>
<tr><td>STATE FACILITIES</td><td>MEDIUM-LOW</td></tr>
<tr><td colspan="2">18% of State Owned facilities are located in areas exposed to medium or higher landslide hazard.
Less than 1% of the State Leased facilities are located in in areas exposed to medium or higher landslide hazard.</td></tr>
<tr><td>FIRST RESPONDERS</td><td>MEDIUM-LOW</td></tr>
<tr><td colspan="2">19% of the Fire Stations are located in areas exposed to medium or higher landslide hazard.
6% of the Law Enforcement facilities are located in areas exposed to medium or higher landslide hazard.
17% of the EMS facilities are located in in areas exposed to medium or higher landslide hazard.</td></tr>
<tr><td>ECONOMIC CONSEQUENCES</td><td>MEDIUM</td></tr>
<tr><td colspan="2">Counties ranked high or medium-high on WaSRI-WF account for 25% of real State GDP.</td></tr>
<tr><td>ENVIRONMENTAL IMPACTS</td><td>MEDIUM</td></tr>
<tr><td colspan="2">22% of critical environmental areas are exposed to landslide hazard. Additionally, big wildfires can lead to significant deterioration of the regional environment, increase flooding, mobilize sediment, and also pose health hazards. Climate changes are stressing Washington forests increasing the overall wildland fire risk.</td></tr>
</table>

Wildfire Hazard Profile

Hazard Description

In 2014, the Carlton Complex Fire started on July 14 as a series of four fires that later merged. Containment was not complete until over a month later, on August 24. The fire burned 256,108 acres, 353 homes and was the largest single fire in Washington state history. The following year, five separate fires in the Okanogan Complex Fire burned 256,657 acres, surpassing the Carlton Complex for size (but never becoming a single fire). At least 45 homes and numerous cabins and outbuildings were burned. These two fires burned large parts of Okanogan County and were part of two back-to-back record fire seasons in the state. Washington's experience with these fires has heavily influenced how the state addresses wildfire mitigation, response, recovery and multi-agency coordination.

The wildland fire season in Washington usually begins in early July and typically culminates in late September with a moisture event; however, wildland fires have occurred in every month of the year. Drought, snow pack, and local weather conditions can expand the length of the fire season. The early and late shoulders of the fire season usually are associated with human-caused fires. Lightning generally is the cause of most fires in the peak fire period of July, August and early September. Historically, wildland fire burns approximately 23,000 acres of state-owned or protected land annually. The cost of wildland fire on these lands is more than $28 million annually in firefighting and damage to timber, habitat, and property, soil mobilization, landslides and flooding. Suppression costs alone cost $60 million for the Carlton Complex fire. Economic costs were estimated at $98 million for that fire.

Large wildfires have an additional public health risk. Wildfire smoke is made up of particulate matter, carbon monoxide and other harmful pollutants from burning trees, plant materials, and combustion of plastics and other chemicals released from burning structures and furnishings. Exposure to fine particulate matter (parts per million 2.5) is a significant health concern, because the small size of the particle allows people to inhale it deep in the lungs where the particles can directly enter the blood stream. The effects of smoke exposure range from eye and respiratory tract irritation to more serious health problems including reduced lung function, bronchitis, exacerbation of asthma and heart failure, and premature death. People with existing heart and lung diseases, older adults, children and pregnant women are especially at risk of smoke-related health problems. Recent studies of wildfire smoke exposure in Washington found a significant relationship between exposure to PM2.5 from wildfire smoke, and an increase in emergency room and outpatient visits for asthma, especially pediatric asthma and other childhood respiratory and chest symptoms, as well as COPD across all age groups, and all respiratory outcomes.[1]

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[1] For more information, see Washington State Department of Health/Chelan-Douglas, Grant, Kittitas and Okanogan Counties (2015), Surveillance Investigation of the Cardiopulmonary Health Effects of the 2012 Wildfires in North Central Washington State; Gan, R. W., B. Ford, W. Lassman, G. Pfister, A. Vaidyanathan, E. Fischer, J. Volckens, J. R.

Lower intensity wildfire is an integral and complex component of the forested ecosystem, helping to maintain forest health, structure, diversity and function (Agee 1993). Unfortunately, changes in land use, coupled with fire suppression, have resulted in higher intensity fires that have minimized the benefits that fires provide. Additionally, accelerating the decline of forest health and transforming them into natural hazard threats that we often need to mitigate.

Wildfires occur when the necessary elements of a fire triangle (figure WF1) come together in a wooded or grassy area: an ignition source is brought into contact with a combustible material, such as vegetation, that is subjected to sufficient heat and has an adequate supply of oxygen from the ambient air. Wildfires are a significant hazard not only in Washington but in many areas across the United States.

A wildfire front is the portion sustaining continuous flaming combustion, where unburned material meets active flames, or the smoldering transition between unburned and burned material. As the front approaches, the fire heats both the surrounding air and woody material through convection and thermal radiation. High-temperature and long-duration surface wildfires encourage flashover or torching: the drying of tree canopies and their subsequent ignition from below.

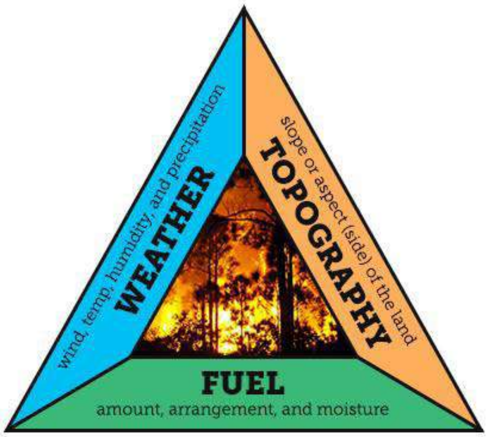

Figure WF 1: Wildfire Pyramid

Wildfires have a rapid forward rate of spread when burning through dense, uninterrupted fuels. They can move as fast as 6.7 mph in forests and 14 mph in grass and range lands, depending on specific fuel time and fuel/weather conditions. Large wildfires may affect air currents in their immediate vicinities by the stack effect: air rises as it is heated, and large wildfires create powerful updrafts that will draw in new, cooler air from surrounding areas in thermal columns. Great vertical differences in temperature and humidity encourage pyrocumulus clouds, strong winds and fire whirls with the force of a tornado, at speeds of more than 80 kilometers per hour (50 mph). Rapid rates of spread, prolific crowning or spotting, the presence of fire whirls, and strong convection columns signify extreme conditions.

There are four main types of fires, which include: ground fires, crawling or surface fires, ladder fires and crown/canopy fires:

- Ground fires are fed by subterranean roots, duff and other buried organic matter. This fuel type is especially susceptible to ignition through spotting. Ground fires typically burn by smoldering and can burn slowly for days to months.
- Crawling or surface fires are fueled by low-lying vegetation such as leaf and timber litter, debris, grass and low-lying shrubbery.

Pierce, and S. Magzamen (2017), Comparison of wildfire smoke estimation methods and associations with cardiopulmonary-related hospital admissions, GeoHealth, 1.

- Ladder fires consume the material between low-level vegetation and tree canopies, such as small trees, downed logs and vines. Kudzu, Old World climbing fern and other invasive plants that scale trees may also encourage ladder fires.
- Crown, canopy or aerial fires burn suspended material at the canopy level, such as tall trees, vines and mosses. The ignition of a crown fire, termed crowning, is dependent on the density of the suspended material, canopy height, canopy continuity, and sufficient surface and ladder fires in order to reach the tree crowns.

Topography, climate and vegetation control the dynamic nature of wildfires (figure WF1) (Falk et al 2007, Collins and Stephens 2010); as such, alteration to one of these elements can exacerbate fire effects upon the landscape.

Topography influences wildfire behavior significantly. The movement of air over the terrain tends to direct a fire's course. Gulches and canyons can funnel air and act as a chimney, intensifying fire behavior and inducing faster rates of spread. Similarly, saddles on ridge tops tend to offer lower resistance to the passage of air and will draw fires. Solar heating of drier, south-facing slopes produces upslope thermal winds that can complicate behavior. Slope is another important factor. If the percentage of uphill slope doubles, the rate at which a wildfire spreads will likely double. On steep slopes, fuels on the uphill side of the fire are closer to the source of heat. In such topography, radiation preheats and dries the fuel faster, thus intensifying fire behavior. Terrain can also inhibit wildfires: fire travels down slope much more slowly than it does upslope, and ridge tops often mark the end of a wildfire's rapid spread.

Fuels are classified by weight or volume (fuel loading) and by type. Fuel loading, often expressed in tons per acre, can be used to describe the amount of vegetative material available. If fuel loading doubles, the energy released also can be expected to double. Each fuel type is provided a burn index, which is an estimate of the amount of potential energy that may be released, the effort required to contain a fire in a given fuel, and the expected flame length. Different fuels have different burn qualities. Some fuels burn more easily or release more energy than others. Grass, for instance, releases relatively little energy, but can sustain very high rates of spread.

Firefighters generally classify wildfire fuels into three types:

- **Ground Fuels:** This vegetation is close to or lying on the ground. Ground fuels include dead grass and leaves, needles, dead branches, twigs and logs.
- **Surface Fuels:** These plants and trees are close to the ground but not actually lying on the ground. They are usually shrubs, grasses, low-hanging branches and anything not located in the high branches of trees. They are also referred to as “ladder fuels” because a fire can move from ground fuels to surface fuels, then onto crown fuels.
- **Crown Fuels:** Crown fuels are found only in the crowns or tops of trees. They do not touch the ground and are usually the high branches of trees. When a wildfire burns in the tops of the trees, it is called a crown fire.

Continuity of fuels is an important factor. Continuity is expressed in terms of both horizontal and vertical dimensions. Horizontal continuity is what can be seen from an aerial photograph and represents the distribution of fuels over the landscape. Vertical continuity links fuels at the ground surface with tree crowns via ladder fuels.

Another essential factor is fuel moisture. Like humidity, fuel moisture is expressed as a percentage of total saturation and varies with antecedent weather. Low fuel moistures indicate the probability of severe fires. Given the same weather conditions, moisture in fuels of different diameters changes at different rates. A 1,000-hour fuel, which has a three to eighth-inch (eight to 20-centimeter) diameter, changes more slowly than a one or 10-hour fuel.

Of all the factors influencing wildfire behavior, weather is the most variable. Extreme weather leads to extreme events, and it is often a moderation of the weather that marks the end of a wildfire's growth and the beginning of successful containment. High temperatures and low humidity can produce very vigorous fire activity. The cooling and higher humidity brought by sunset can dramatically quiet fire behavior. Even wind shifts can contribute to dramatic fire growth.

Fronts and thunderstorms can produce winds that are capable of radical and sudden changes in speed and direction, causing similar changes in fire activity. Large fires are also capable of creating their own weather. A fire’s rate of spread varies directly with wind velocity. Winds may play a dominant role in directing the course of a fire. The radical and devastating effect that wind can have on fire behavior is a primary safety concern for firefighters. In July 1994, a sudden change in wind speed and direction on Storm King Mountain led to a blowup that claimed the lives of 14 firefighters. The most damaging firestorms are usually marked by high winds. The complexity of local weather in mountainous areas, combined with the impact of fire generating its own weather, makes fire-weather ‘spot forecasts’ a necessity for firefighter safety.

Wildfire can advance tangentially to the main front to form a flanking front or burn in the opposite direction of the main front by backing. They may also spread by jumping or spotting, as winds and vertical convection columns carry firebrands (hot wood embers) and other burning materials through the air over roads, rivers and other barriers that may otherwise act as firebreaks. Torching and fires in tree canopies encourage spotting, and dry ground fuels that surround a wildfire are especially vulnerable to ignition from firebrands. Spotting can create spot fires as hot embers and firebrands ignite fuels downwind from the fire.

Wildfire Location, Extent, and Magnitude

Wildfires are described in terms of fire regime, frequency, extent and severity in the tables below (FRCC Guidebook 2010). Fire regime is a term that describes fire occurrence in terms of frequency, extent, severity, seasonality and synergy with other disturbance agents. Fire frequency is defined as the number of times a fire occurs within a specific area. Fire extent is the total area burned by a single wildfire. Fire severity describes the effects upon the landscape - degree to which a site has been altered or disrupted by fire; loosely, a product of fire intensity and residence time. Vegetation burn severity describes the effects of fire on the vegetation. It consists of four classifications:

unburnt, low, moderate (mix) and high severity. Soil burn severity describes the effects of fire on the soil. It includes four classifications: unburnt, low, moderate (mix) and high severity.

Qualitatively, wildfire hazard may be described by the fire environment surrounding the resource, such as the fuel, weather, topography and ignition characteristics. Quantitatively, wildfire hazard is described in a number of ways depending on the adopted modeling approach. Some researchers describe it as the probability distribution of a fire characteristic, usually wildfire intensity. A location likely to burn with high intensity, in this approach, has high hazard. Hazard, however, is but one component of wildfire risk, and therefore other researchers recommend a more broader approach. Finney (2005) provides a quantitative definition of wildfire risk that integrates information on burn likelihood, fire intensity and magnitude of resource response to fire. This approach aligns with ecological risk assessment paradigms based on the analysis of exposure and effects (Fairbrother and Turnley 2005). Wildfire exposure analysis typically explores the possible spatial interactions of fire-susceptible resources with fire occurrence and behavior metrics, and fire effects analysis explores the potential magnitude of wildfire-caused damages (Thompson and Calkin 2011). In fire-adapted ecosystems, exposure and effects analysis highlights where fire may play an ecologically beneficial role and be promoted. These assessments can be used to help plan risk mitigation activities across the wildfire management spectrum, including ignition prevention efforts, proactive hazardous fuels reduction, suppression response planning and evacuation planning (Dennison et al. 2007).

Wildland fires can also be classified by their intensity or the rate of heat energy release per unit time per unit length of fire front. High intensity fires, including most “Crown” fires, can have a major negative impact on soil including erosion, productivity and hydrophobicity. Lower intensity fires can have a beneficial impact on the environment and can be considered part of a natural historic wildland fire cycle (Gergel et al. 2017).

The leading theme that emerged from this research was that reducing risks are not solely dependent on the community surviving large, severe, and high intensity wildland fires and associated flooding, but also on preventing soil degradation and forest restoration. Healthy soils are an important component of resilient forest; they store moisture, provide nutrients and anchor trees. Consequently, risk reduction and community resilience depends on soil stability, vegetative cover, and maintaining healthy soils composed of organic matter and microorganisms, which can enable forest regeneration.

Another approach to evaluate wildfire risk focuses on the areas where wildfire is likely to pose greatest risk to the built environment. The wildland–urban interface (WUI) is the zone where structures and other human development meet and intermingle with undeveloped wildland or vegetative fuels. As such this zone is at greatest threat from wildfire events. The character of the WUI ranges from urban areas adjoining wildlands to isolated ranches or cabins. The WUI is thus a focal area for human environment conflicts, such as the destruction of homes by wildfires, habitat fragmentation, introduction of exotic species and biodiversity decline. Of the 11 Western States, Washington has the largest area of developed WUI (Ray 2016). As per the same study, 29 percent of the WUI in the state is developed with an estimated 951,000 homes in this region. Figure WF2 provides the county level view of the WUI development in the state.

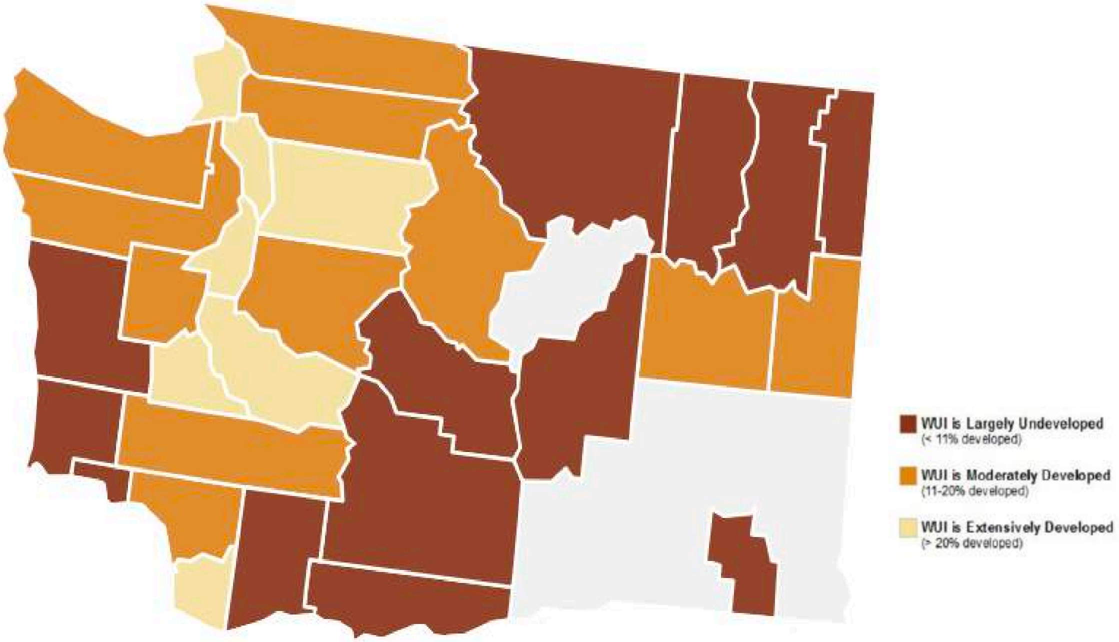

Figure WF 2: WUI Development Status in 2016

**Grey areas indicate lack of sufficient data*
Source: https://headwaterseconomics.org/dataviz/wui-development-and-wildfire-costs/

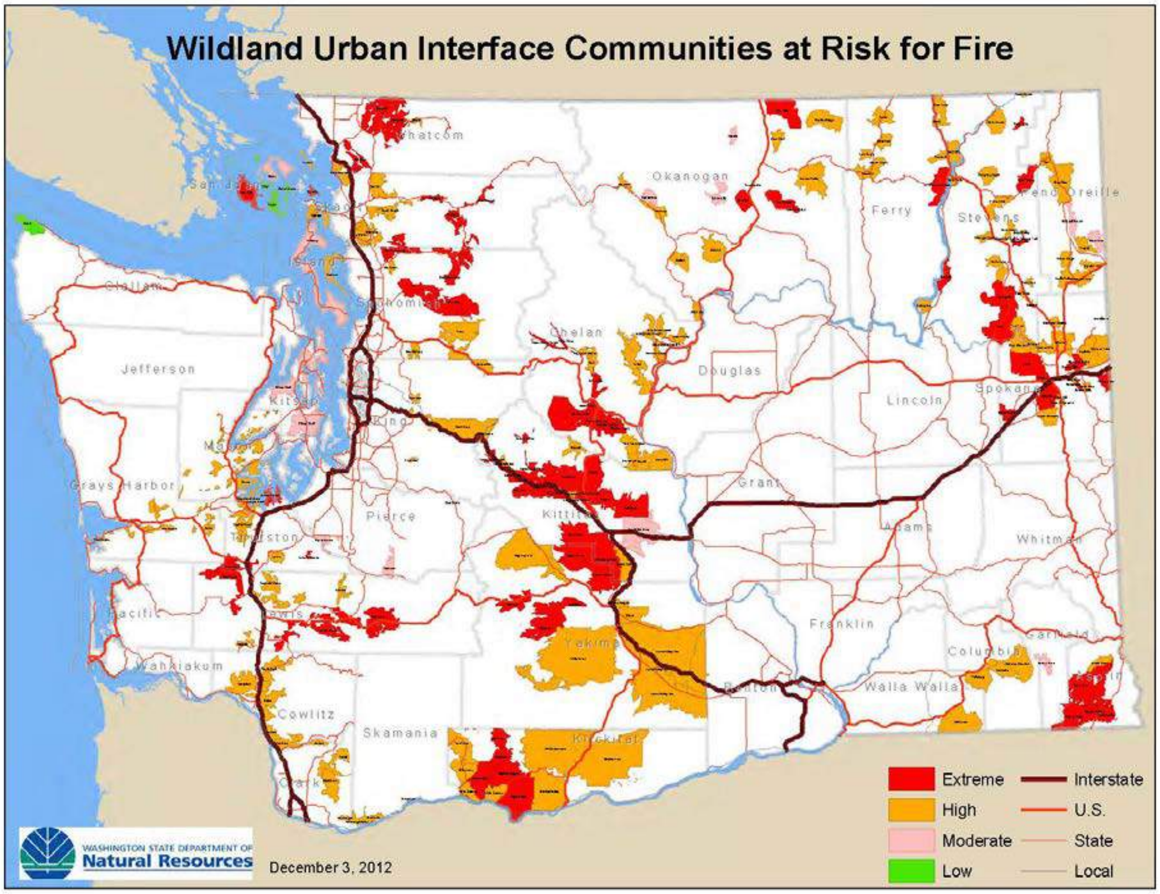

Figure WF 3: Wildland-Urban Interface Communities at Risk for Fire (Source: DNR 2012)

Headwaters Economics has developed an interactive mapping tool that identifies communities threatened by wildfires from 2000-2014, also showing the different sizes of wildfires and distances from nearby communities (http://headwaterseconomics.org/dataviz/communities-wildfire-threat). Distance measurements were calculated using Census Designated Place boundaries from the 2015 TIGER/Line files. Based on this dataset, 108 communities experienced wildfires of 5,000+ acres within less than 10 miles from their community between 2000-2014. Wenatchee experienced the most (12) such fires during this 4-year period, followed by East Wenatchee, Sunnyslope and Nespelem communities that experienced 10 such fires during the same period. The highest number of 1,000-5,000 acre wildfires within 2 miles were experienced by Okanogan (three fires between 2000 and 2014). Chelan, White Salmon, Dallesport and Lyle each experienced two fires of 1,000-5,000 acres within 2 miles of the city boundary between 2000 and 2014. White Swan and Wishram each experienced two wildfires of 100-1,000 acres within 700 feett from town during the same period.

Wildfires Near Cities in Washington State (2000 2014)

	City or Town	Num. of 100 1,000 ac. wildfires that occurred < 700 ft. from town	Num. of 1,000 5,000 ac. wildfires that occurred < 2 mi. from town	Num. of 5,000+ ac. wildfires that occurred < 10 mi. from town
1	Spokane	0	1	0
2	Yakima	0	1	2
3	Spokane Valley	0	1	0
4	Kennewick	0	0	1
5	Pasco	0	0	1
6	Richland	1	0	2
7	Wenatchee	0	0	12
8	Walla Walla	0	0	1
9	Ellensburg	0	0	2
10	Sunnyside	0	0	2
11	East Wenatchee	0	0	10
12	West Richland	1	0	2
13	Grandview	0	0	1
14	Cheney	0	0	1
15	Toppenish	0	0	1
16	Ephrata	1	1	0
17	Selah	0	0	1
18	Quincy	0	0	2
19	Finley	0	0	1
20	Terrace Heights	0	0	2
21	Union Gap	0	1	2
22	Wapato	0	0	1
23	Omak	0	1	9
24	Mattawa	0	0	1
25	Chelan	0	2	8
26	Ahtanum	0	1	1
27	Sunnyslope	0	0	10
28	Moxee	0	0	1
29	Goldendale	0	0	3
30	Granger	0	0	1
31	Burbank	0	0	1
32	Cashmere	0	0	9
33	Benton City	0	1	2
34	Zillah	0	0	1
35	Dayton	1	0	1
36	Gleed	0	0	1
37	Okanogan	0	3	8

Wildfires Near Cities in Washington State (2000 2014)

	City or Town	Num. of 100 1,000 ac. wildfires that occurred < 700 ft. from town	Num. of 1,000 5,000 ac. wildfires that occurred < 2 mi. from town	Num. of 5,000+ ac. wildfires that occurred < 10 mi. from town
38	Bridgeport	0	0	4
39	Cle Elum	0	0	2
40	Leavenworth	0	0	4
41	Brewster	0	0	7
42	White Salmon	0	2	1
43	Davenport	0	0	1
44	Waterville	0	0	5
45	Desert Aire	0	0	2
46	Pomeroy	0	0	2
47	Summitview	0	0	1
48	Coulee Dam	0	1	5
49	Manson	0	0	8
50	Kittitas	0	0	2
51	Basin City	0	0	1
52	Tonasket	0	0	1
53	Dallesport	0	2	3
54	Entiat	0	1	5
55	South Wenatchee	0	0	9
56	Buena	0	0	1
57	Tieton	0	0	1
58	Waitsburg	0	0	1
59	Twisp	0	0	2
60	Grand Coulee	0	0	5
61	Electric City	0	0	5
62	Bingen	0	1	1
63	Naches	0	0	1
64	Roslyn	0	0	1
65	Odessa	0	0	1
66	George	0	0	1
67	North Omak	0	1	9
68	White Swan	2	0	0
69	Wilbur	0	0	1
70	Rock Island	0	1	4
71	Inchelium	1	1	0
72	South Cle Elum	0	0	1
73	Riverside	0	1	3
74	Curlew Lake	0	0	1
75	Pateros	0	0	6
76	Cowiche	0	0	1

Wildfires Near Cities in Washington State (2000 2014)

	City or Town	Num. of 100 1,000 ac. wildfires that occurred < 700 ft. from town	Num. of 1,000 5,000 ac. wildfires that occurred < 2 mi. from town	Num. of 5,000+ ac. wildfires that occurred < 10 mi. from town
77	Sprague	0	0	1
78	Trout Lake	0	0	2
79	Malott	0	1	6
80	Lyle	0	2	1
81	Winthrop	0	0	2
82	Wishram	2	0	1
83	Elmer City	1	1	5
84	Harrington	0	0	1
85	Thorp	0	0	3
86	Wilson Creek	0	0	1
87	Dixie	0	0	1
88	Creston	0	0	1
89	Eschbach	0	0	1
90	Tampico	0	0	1
91	Kahlotus	0	0	1
92	Nespelem Community	0	1	10
93	Outlook	0	0	2
94	Nespelem	0	0	6
95	Keller	0	0	5
96	Centerville	0	0	1
97	Chelan Falls	0	0	3
98	Parker	0	0	1
99	Twin Lakes	0	0	1
100	Loomis	0	0	1
101	Roosevelt	0	1	5
102	Donald	0	0	1
103	Conconully	0	0	1
104	Torboy	0	0	1
105	Starbuck	0	0	1
106	Lamont	0	0	1
107	Bickleton	0	0	4
108	Krupp	1	0	1
109	Curlew	0	0	2
110	Danville	0	0	1
111	Orient	0	0	1
112	Wallula	0	0	1
113	Disautel	0	0	6

FireWise Program and Fire Adapted Communities

The FireWise program encourages local solutions by homeowners, community leaders, planners, developers, firefighters, and others to protect people and property from the risk of wildfire by creating defensible spaces around structures and by minimizing fire ignitable building materials. According to the Department of Natural Resources (DNR), as many as 80 percent of homes lost to wildland fire could have been saved if brush around the structure was cleared. With the help and guidance of DNR fire prevention staff, 142 Washington communities have earned recognition as a FireWise Community for their wildfire prevention work. Washington state has the second-most FireWise Communities in the nation. Forty-nine communities have mitigation plans or Community Wildfire Protection Plans (CWPP) as part of their fire prevention strategies for Washington's wildland urban interface communities. CWPP are community-driven plans for prioritized fuel reduction and treatment of structural ignitability.

Fire Adapted Communities are communities that work to prepare residents and take community-based actions to coexist with wildfire. Many of these communities participate in the Fire Adapted Community Learning Network (FACNET). They can be an excellent resource for community-based wildfire mitigation projects. The Washington chapter was the first state-level expansion of the national FACNET, coming together in 2015 in response to the urgent need for integrated wildfire resilience strategies, clearly demonstrated by the 2014 fire season (FEMA 2015).

Washington DNR regularly makes grants to communities to fund fuel mitigation in advance of each fire season. Recipients contribute their own labor and equipment to match $1-$15 thousand in state grants. Additional funding and technical assistance is occasionally available for the development of Community Wildfire Protection Plans (CWPP). Washington Emergency Management Division (EMD) recommends developing integrated mitigation plans with elements similar to CWPPs as this will help keep both planning tools relevant and up to date over time.

Also, embracing Fire Adaptive Communities (FAC) and FireWise practices enable suppression efforts to be diverted from protecting human settlements to protecting forests and the ecosystem service on we which we enjoy and depend on.

Past Occurrences

In the state of Washington since 2000, the number of fires over 1,000 acres has increased from a couple early in the first years of the century to 36 and 25 in 2015 and 2016, respectively. Large fires, those that burn over 1,000 acres, are no longer an anomaly. Since 2006, Washington state has experienced an increase in large fires, mainly in north-central Washington. In 2006, the Tripod Complex Fire burned over 180,000 acres, followed by the largest wildfire in the state to date, the Carlton Complex fire (256,108 acres) in 2014 and the Diamond Creek Fire burned 128,272 acres in 2017.

Climate change, coupled with the current fuels and vegetation status of the forest, suggest that these types of fires will continue to degrade the landscape unless proper management policies are implemented. Our winters are becoming shorter and wetter, with less snow, while summers are becoming drier and longer. This process is resulting in the generation of flasher fuels, uncharacteristically denser forests, and are stressing normal regenerative processes and increasing wildland fire risk. Accordingly, forests are becoming less resilient.

Exceedingly intense and high severity forests hinder regeneration. Regenerative tipping points can be crossed. In order for fires to be less intense and provide some ecosystem benefits, forest composition and structures, similar to historical forest conditions, need to be restored by using a variety of management practices such as harvesting, thinning, prescribed fires, etc.

Without such an emphasis on forest health, high-severity fires have the potential to permanently devastate forest resources and their ecosystem services. This is even true for forests west of the Cascades that have traditionally been spared from wildfires.

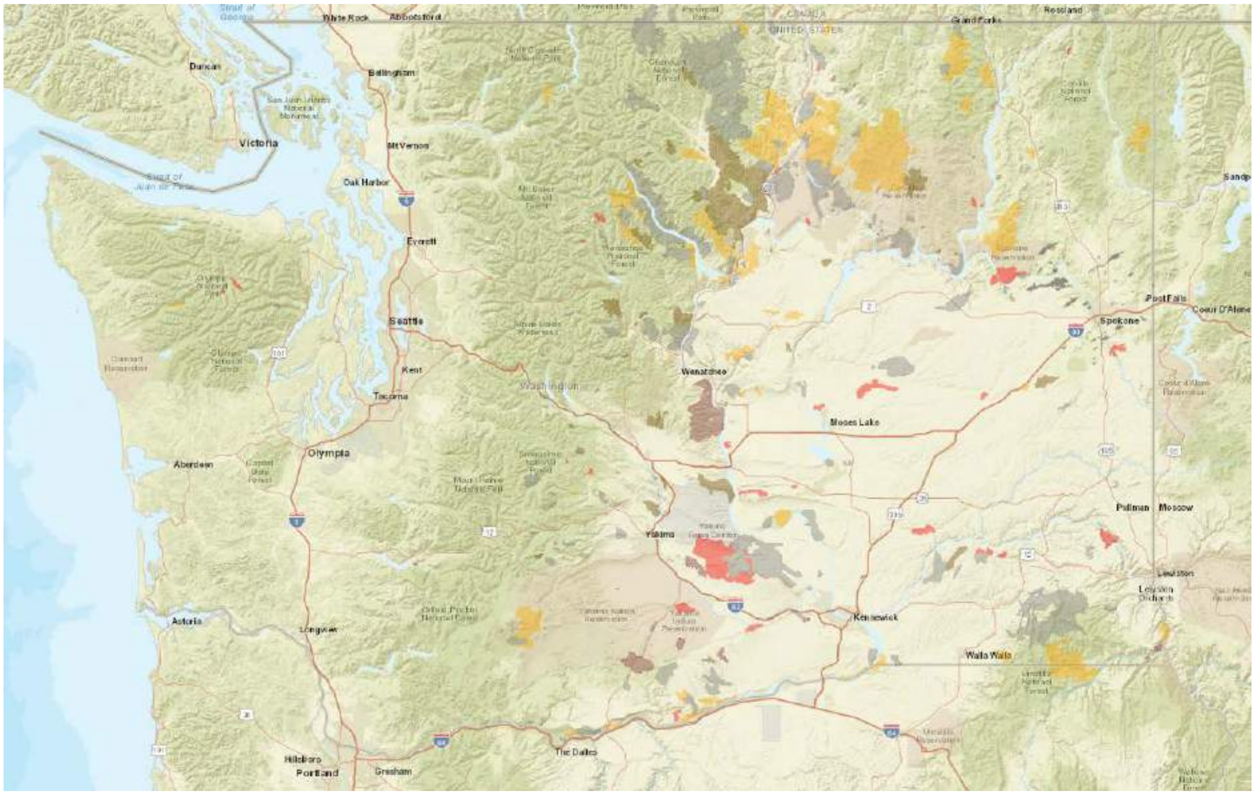

FIGURE WF 4: LARGE WASHINGTON FIRES, 1973-2016 (SOURCE: DNR)

Between 1960 and 2017 the state experienced 170 wildfire events, with Okanogan county experiencing the most (35) events. Douglas, Chelan, Lincoln, Grant, Spokane and Adams counties also experienced at least 10 wildfire events during this period. The wildfires resulted in approximately $309 million worth of property damages, and 18 casualties. Most property damage was reported in Okanogan County, followed by Douglas and Chelan counties. Not all counties experienced wildfire events, with 15 counties not reporting any events between 1960 and 2017.

Wildfire Events and Damages (1960 2017)

County	Number of Events	Total Property Damage (Adj. to 2016)	Total Injuries	Total Fatalities
Adams	10	$107,471	1	0
Asotin	1	$4,732	0	0
Benton	0	$0	0	0
Chelan	20	$21,416,106	1	0
Clallam	0	$0	0	0
Clark	0	$0	0	0
Columbia	1	$4,732	0	0
Cowlitz	0	$0	0	0
Douglas	23	$128,982,819	1	0
Ferry	5	$648,235	0	0
Franklin	2	$62,290	0	0
Garfield	1	$4,732	0	0
Grant	12	$385,848	0	0
Grays Harbor	1	$412,415	0	0
Island	0	$0	0	0
Jefferson	1	$0	0	0
King	0	$0	0	0
Kitsap	1	$0	0	0
Kittitas	5	$2,951,228	1.5	0
Klickitat	4	$5,391,658	0	0
Lewis	0	$0	0	0
Lincoln	14	$613,502	0	0
Mason	2	$412,415	0	0
Okanogan	35	$134,963,197	6	4
Pacific	1	$0	0	0
Pend Oreille	3	$49,463	0	0
Pierce	0	$0	0	0
San Juan	0	$0	0	0
Skagit	0	$0	0	0
Skamania	0	$0	0	0
Snohomish	0	$0	0	0
Spokane	11	$1,857,536	0	0
Stevens	5	$733,454	0	0
Thurston	0	$0	0	0
Wahkiakum	0	$0	0	0
Walla Walla	1	$4,732	0	0
Whatcom	0	$0	0	0
Whitman	3	$184,638	0	0
Yakima	8	$9,946,594	3.5	0
Grand Total	170	$309,137,793	14	4

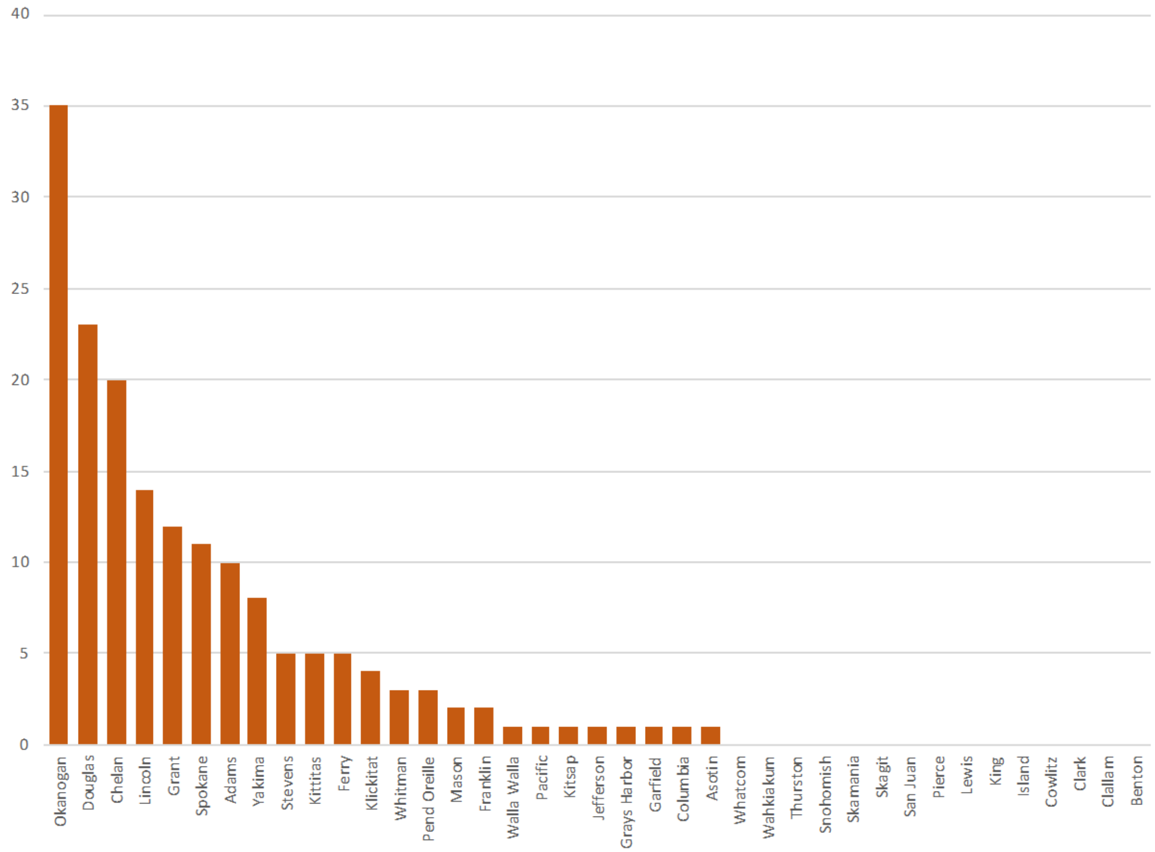

FIGURE WF 5: NUMBER OF SIGNIFICANT WILDFIRE EVENTS (1960-2017)

The following is a list of major wildfire related FEMA declared disasters in Washington state between 1997 and 2017. These include the four types of declarations – Major Disaster Declaration, Emergency Declaration, Fire Management Assistance Declaration and Fire Suppression Authorization. Another key metric of historic fire activity is fire mobilizations. Since 1994, there have been 204 Mobilization declarations, including 202 fires, a motorcycle rally and the Seattle World Trade Organization Protests. Mobilization costs from 1994-2017 total approximately $162,517,520 (not including cost incurred by DNR or any Federal entity):

Annual Averages 2013-2017

- Mobilization Events: 88
- Annual Cost: $16,099,890
- Cost per event: $914,766
- Hours Mobilized per Year: 2142.75
- Event Duration: 121.75

Annual Averages 2008-2012

- Mobilization Events: 56
- Annual Cost: $6,389,357
- Cost per Event: $570,478

- Hours Mobilized per Year: 1082.5
- Event Duration: 96.6

In recent years, the costs of fire mobilizations have gone up along with larger numbers of events as fires have become larger and have taken longer to contain.

FEMA Disaster Declarations for Wildfire

- Washington Jolly Mountain Fire (FM-5200)
    - Incident period: September 2, 2017 to September 22, 2017
    - Fire Management Assistance Declaration declared on September 2, 2017
- Washington South Wenas Fire (FM-5187)
    - Incident period: June 27, 2017
    - Fire Management Assistance Declaration declared on June 28, 2017
- Washington Spromberg Fire (FM-5182)
    - Incident period: May 23, 2017
    - Fire Management Assistance Declaration declared on May 23, 2017
- Washington Suncrest Fire (FM-5152)
    - Incident period: August 27, 2016 to August 30, 2016
    - Fire Management Assistance Declaration declared on August 28, 2016
- Washington Yale Fire (FM-5149)
    - Incident period: August 21, 2016 to August 29, 2016
    - Fire Management Assistance Declaration declared on August 22, 2016
- Washington Wellesley Fire (FM-5148)
    - Incident period: August 21, 2016 to August 24, 2016
    - Fire Management Assistance Declaration declared on August 22, 2016
- Washington South Ward Gap Fire (FM-5142)
    - Incident period: July 31, 2016 to August 3, 2016
    - Fire Management Assistance Declaration declared on August 1, 2016
- Washington Wildfires and Mudslides (DR-4243)
    - Incident period: August 9, 2015 to September 10, 2015
    - Major Disaster Declaration declared on October 20, 2015
- Washington Wildfires (EM-3372)
    - Incident period: August 13, 2015 to September 10, 2015
    - Emergency Declaration declared on August 21, 2015
- Washington Hansel Fire (FM-5072)
    - Incident period: August 2, 2014
    - Fire Management Assistance Declaration declared on August 6, 2014
- Washington Wildfires (DR-4188)
    - Incident period: July 9, 2014 to August 6, 2014
    - Major Disaster Declaration declared on August 11, 2014
- Washington Snag Canyon Fire (FM-5071)
    - Incident period: August 2, 2014
    - Fire Management Assistance Declaration declared on August 3, 2014
- Washington Wildfires (EM-3371)
    - Incident period: July 9, 2014 to August 5, 2014

  - Emergency Declaration declared on July 23, 2014
- Washington Watermelon Hill Fire (FM-5063)
  - Incident period: July 19, 2014 to July 22, 2014
  - Fire Management Assistance Declaration declared on July 19, 2014
- Washington Saddle Mountain Fire (FM-5064)
  - Incident period: July 19, 2014 to July 20, 2014
  - Fire Management Assistance Declaration declared on July 19, 2014
- Washington Carlton Complex Fire (FM-5062)
  - Incident period: July 16, 2014
  - Fire Management Assistance Declaration declared on July 17, 2014
- Washington Chiwaukum Fire (FM-5061)
  - Incident period: July 15, 2014
  - Fire Management Assistance Declaration declared on July 17, 2014
- Washington Mills Canyon Fire (FM-5059)
  - Incident period: July 8, 2014
  - Fire Management Assistance Declaration declared on July 10, 2014
- Washington Lake Spokane Fire (FM-5058)
  - Incident period: July 9, 2014 to July 14, 2014
  - Fire Management Assistance Declaration declared on July 10, 2014
- Washington Eagle Fire (FM-5048)
  - Incident period: August 20, 2013 to August 28, 2013
  - Fire Management Assistance Declaration declared on August 21, 2013
- Washington Mile Post 10 Fire (FM-5042)
  - Incident period: August 10, 2013 to August 14, 2013
  - Fire Management Assistance Declaration declared on August 10, 2013
- Washington Colockum Tarps Fire (FM-5038)
  - Incident period: July 27, 2013 to August 14, 2013
  - Fire Management Assistance Declaration declared on July 30, 2013
- Washington Monastery Fire Complex (FM-2966)
  - Incident period: September 8, 2011
  - Fire Management Assistance Declaration declared on September 8, 2011
- Washington Slide Creek Fire (FM-2854)
  - Incident period: August 26, 2010 to August 31, 2010
  - Fire Management Assistance Declaration declared on August 27, 2010
- Washington Cowiche Mills Fire (FM-2848)
  - Incident period: July 18, 2010 to July 21, 2010
  - Fire Management Assistance Declaration declared on July 19, 2010
- Washington Oden Road Fire (FM-2826)
  - Incident period: August 21, 2009 to August 26, 2009
  - Fire Management Assistance Declaration declared on August 22, 2009
- Washington Dry Creek Fire Complex (FM-2827)
  - Incident period: August 21, 2009 to August 25, 2009
  - Fire Management Assistance Declaration declared on August 22, 2009
- Washington Union Valley Fire (FM-2823)
  - Incident period: July 28, 2009 to August 2, 2009

  - Fire Management Assistance Declaration declared on July 29, 2009
- Washington Badger Mountain Fire Complex (FM-2784)
  - Incident period: July 10, 2008 to July 18, 2008
  - Fire Management Assistance Declaration declared on July 11, 2008
- Washington Spokane Valley Fire (FM-2783)
  - Incident period: July 10, 2008 to July 19, 2008
  - Fire Management Assistance Declaration declared on July 11, 2008
- Washington Broughton Fire (FM-2731)
  - Incident period: September 20, 2007 to September 23, 2007
  - Fire Management Assistance Declaration declared on September 21, 2007
- Washington Tunk Grade Fire (FM-2714)
  - Incident period: July 16, 2007 to July 20, 2007
  - Fire Management Assistance Declaration declared on July 16, 2007
- Washington Easy Street Fire (FM-2711)
  - Incident period: July 8, 2007 to July 10, 2007
  - Fire Management Assistance Declaration declared on July 08, 2007
- Washington Flick Creek Fire (FM-2674)
  - Incident period: September 9, 2006 to September 16, 2006
  - Fire Management Assistance Declaration declared on September 11, 2006
- Washington Columbia Fire Complex (FM-2668)
  - Incident period: August 22, 2006
  - Fire Management Assistance Declaration declared on August 22, 2006
- Washington Valley Mill Fire (FM-2663)
  - Incident period: August 8, 2006 to August 11, 2006
  - Fire Management Assistance Declaration declared on August 8, 2006
- Washington School Fire (FM-2575)
  - Incident period: August 7, 2005 to August 19, 2005
  - Fire Management Assistance Declaration declared on August 7, 2005
- Washington Dirty Face Fire (FM-2572)
  - Incident period: July 31, 2005 to August 8, 2005
  - Fire Management Assistance Declaration declared on August 1, 2005
- Washington Bowie Road Fire (FM-2186)
  - Incident period: August 11, 1996
  - Fire Management Assistance Declaration declared on August 11, 1996
- Washington Cowlitz County (FM-2237)
  - Incident period: September 3, 1998
  - Fire Management Assistance Declaration declared on September 3, 1998
- Washington Columbia County (FM-2248)
  - Incident period: September 25, 1998
  - Fire Management Assistance Declaration declared on September 25, 1998
- Washington Grassland & Forest Fire (FM-2002)
  - Incident period: July 18, 1970
  - Fire Management Assistance Declaration declared on July 18, 1970
- Washington Riverside Fire (FM-2101)
  - Incident period: July 11, 1994

  - Fire Management Assistance Declaration declared on July 11, 1994
- Washington Salmon Creek Fire (FM-2033)
  - Incident period: July 23, 1979
  - Fire Management Assistance Declaration declared on July 23, 1979
- Washington Tyee Wildfire (FM-2103)
  - Incident period: July 24, 1994
  - Fire Management Assistance Declaration declared on July 26, 1994
- Washington Tonasket/Baker Fire (FM-2058)
  - Incident period: August 30, 1985
  - Fire Management Assistance Declaration declared on August 30, 1985
- Washington Hatchery Creek/Round Mountain Fire (FM-2104)
  - Incident period: July 26, 1994
  - Fire Management Assistance Declaration declared on July 28, 1994
- Washington Dinkleman Fire (FM-2070)
  - Incident period: September 6, 1988
  - Fire Management Assistance Declaration declared on September 6, 1988
- Washington White Salmon Fire (FM-2105)
  - Incident period: July 26, 1994
  - Fire Management Assistance Declaration declared on July 29, 1994
- Washington Eastern Washington Fires (FM-2079)
  - Incident period: October 16, 1991
  - Fire Management Assistance Declaration declared on October 18, 1991
- Washington Skookum Fire (FM-2085)
  - Incident period: August 4, 1992
  - Fire Management Assistance Declaration declared on August 6, 1992
- Washington Fires (DR-922)
  - Incident period: October 16, 1991 to October 24, 1991
  - Major Disaster Declaration declared on November 13, 1991
- Washington Fischer Fire (FM-2543)
  - Incident period: August 11, 2004 to August 26, 2004
  - Fire Management Assistance Declaration declared on August 11, 2004
- Washington Mud Lake Fire (FM-2546)
  - Incident period: August 12, 2004 to August 16, 2004
  - Fire Management Assistance Declaration declared on August 12, 2004
- Washington Deep Harbor Fire (FM-2537)
  - Incident period: July 30, 2004 to August 5, 2004
  - Fire Management Assistance Declaration declared on July 30, 2004
- Washington Elk Heights Fire (FM-2538)
  - Incident period: July 30, 2004 to August 4, 2004
  - Fire Management Assistance Declaration declared on July 30, 2004
- Washington Beebe Fire (FM-2527)
  - Incident period: July 5, 2004 to July 9, 2004
  - Fire Management Assistance Declaration declared on July 6, 2004
- Washington Needle Fire (FM-2498)
  - Incident period: September 5, 2003 to September 17, 2003

  - Fire Management Assistance Declaration declared on September 6, 2003
- Washington Okanogan City Fire (FM-2481)
  - Incident period: July 15, 2003 to July 18, 2003
  - Fire Management Assistance Declaration declared on July 16, 2003
- Washington Middle Fork Fire (FM-2477)
  - Incident period: July 11, 2003 to July 19, 2003
  - Fire Management Assistance Declaration declared on July 12, 2003
- Washington Pickens Fire (FM-2451)
  - Incident period: July 24, 2002 to July 26, 2002
  - Fire Management Assistance Declaration declared on July 25, 2002
- Washington Deer Point Fire (FM-2449)
  - Incident period: July 20, 2002 to July 27, 2002
  - Fire Management Assistance Declaration declared on July 20, 2002
- Washington Rex Creek Fire Complex (FM-2379)
  - Incident period: August 13, 2001 to August 31, 2001
  - Fire Management Assistance Declaration declared on August 17, 2001
- Washington Tonasket Fire Complex (FM-2376)
  - Incident period: August 14, 2001 to August 29, 2001
  - Fire Management Assistance Declaration declared on August 16, 2001
- Washington Spruce Dome Fire Complex (FM-2377)
  - Incident period: August 15, 2001 to August 23, 2001
  - Fire Management Assistance Declaration declared on August 16, 2001
- Washington Brewster Fire Complex (FM-2373)
  - Incident period: August 13, 2001 to August 21, 2001
  - Fire Management Assistance Declaration declared on August 14, 2001
- Washington Icicle Fire Complex (FM-2374)
  - Incident period: August 14, 2001 to August 21, 2001
  - Fire Management Assistance Declaration declared on August 14, 2001
- Washington Mt. Leona Fire Complex (FM-2378)
  - Incident period: August 16, 2001 to August 25, 2001
  - Fire Management Assistance Declaration declared on August 17, 2001
- Washington Virginia Lakes Fire Complex (FM-2372)
  - Incident period: August 13, 2001 to August 29, 2001
  - Fire Management Assistance Declaration declared on August 14, 2001
- Washington Union Valley Fire (FM-2368)
  - Incident period: July 28, 2001 to August 4, 2001
  - Fire Management Assistance Declaration declared on July 28, 2001
- Washington Mule Dry Fire (FM-2323)
  - Incident period: August 23, 2000 to August 27, 2000
  - Fire Management Assistance Declaration declared on August 25, 2000
- Washington Two Fork Fire (FM-2311)
  - Incident period: June 28, 2000
  - Fire Management Assistance Declaration declared on February 29, 2000
- Washington Rocky Hull Fire (FM-2313)
  - Incident period: July 22, 2000

    - Fire Management Assistance Declaration declared on July 22, 2000
- Washington Cleveland County Fire (FM-2225)
    - Incident period: July 28, 1998 to July 31, 1998
    - Fire Management Assistance Declaration declared on July 28, 1998
- Washington Olympia Command Fire (FM-2194)
    - Incident period: September 26, 1997
    - Fire Management Assistance Declaration declared on August 27, 1997
- Washington Tum-Tum Fire (FM-2193)
    - Incident period: August 14, 1997
    - Fire Management Assistance Declaration declared on August 14, 1997
- Washington Benton City Fire (FM-2192)
    - Incident period: July 21, 1997
    - Fire Management Assistance Declaration declared on July 21, 1997

Between 2000-2016, Chelan county has received the most federal fire related disaster declarations followed by Okanogan county (FEMA: Disaster Declarations for States and Counties, n.d.).

Federal Wildfire Declarations (2000 2016)	
County	**Number of Wildfire Related Federal Declarations**
Adams	0
Asotin	1
Benton	3
Chelan	27
Clallam	0
Clark	0
Columbia	2
Cowlitz	0
Douglas	5
Ferry	6
Franklin	0
Garfield	1
Grant	1
Grays Harbor	0
Island	0
Jefferson	0
King	0
Kitsap	0
Kittitas	7
Klickitat	6
Lewis	0
Lincoln	2
Mason	0
Okanogan	18
Pacific	0

Federal Wildfire Declarations (2000 2016)	
County	Number of Wildfire Related Federal Declarations
Pend Oreille	2
Pierce	0
San Juan	0
Skagit	1
Skamania	2
Snohomish	0
Spokane	5
Stevens	7
Thurston	0
Wahkiakum	0
Walla Walla	2
Whatcom	2
Whitman	0
Yakima	8
Washington State	108

Based on the available data, August seems to be the peak month for wildfire activity in the state. Most of the above fires were reported in the months of July and August (80 percent).

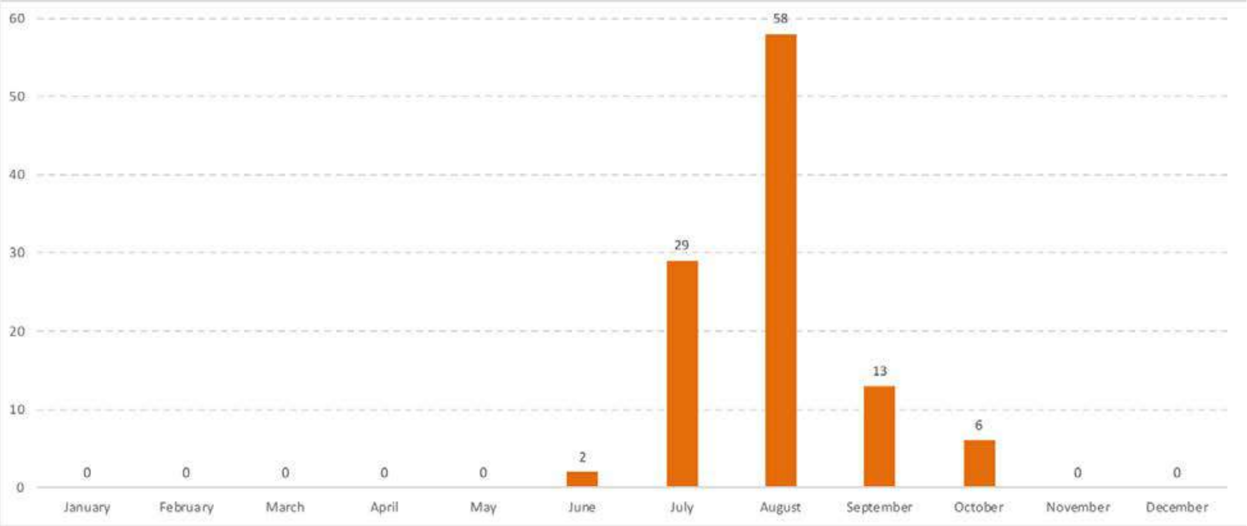

FIGURE WF 6: MONTHLY WILDFIRE ACTIVITY (2000-2017)

Since 2000, the state has experienced at least one significant wildfire (resulting in federal declaration) every year. In 10 of these years, there have been multiple wildfire events (four or more), and three times the state experienced 10 or more wildfire events in the same year. In the year 2015, the state experienced maximum number of wildfire events (36). Based on the past records since 2000, the likelihood of a major wildfire in any given year is one. That is, at least one major wildfire is likely to occur annually. The likelihood of multiple (two or more) wildfires in any given year is 0.94. Thus, multiple wildfires in a year are very likely. The likelihood of four or more wildfires in a year is 0.60. That is there is greater than 50 percent probability that the state will experience four or more wildfires in any given year.

Years with at least One Major Wildfire Event (2000 2017)

Year	Total Major Events
2000	4
2001	8
2002	2
2003	3
2004	5
2005	3
2006	4
2007	3
2008	2
2009	4
2010	2
2011	1
2012	10
2013	4
2014	13
2015	36
2016	4
Total	108

Washington State Department of Natural Resources also maintains a detailed database of all wildfire events since 1970 that have occurred on lands protected by the Department. Based on this dataset, a total of 44,346 wildfires have been recorded since 1970 (through May 2018). It is highlighted that this dataset includes all events that may or may not have had any significant impact on the local community. Overall, it does provide a general indication of areas where wildfires have historically occurred. Spokane County has recorded the maximum number of wildfires since 1970, followed by Stevens and Okanogan counties. Thurston, Klickitat and Kittitas counties have also averaged more than 40 wildfire events annually since 1970.

Wildfires in Washington State on lands protected by DNR (1970 May 2018)

County	Number of Wildfires
Adams	2
Asotin	122
Benton	258
Chelan	1102
Clallam	1036
Clark	886
Columbia	436
Cowlitz	1259

Wildfires in Washington State on lands protected by DNR (1970 May 2018)

County	Number of Wildfires
Douglas	242
Ferry	764
Franklin	11
Garfield	32
Grant	155
Grays Harbor	1031
Island	730
Jefferson	593
King	814
Kitsap	911
Kittitas	2005
Klickitat	2216
Lewis	1596
Lincoln	486
Mason	1687
Okanogan	3302
Pacific	825
Pend Oreille	1372
Pierce	1267
San Juan	534
Skagit	890
Skamania	951
Snohomish	898
Spokane	6170
Stevens	5418
Thurston	2837
Wahkiakum	157
Walla Walla	60
Whatcom	553
Whitman	6
Yakima	732
Washington Total	44346

Relationship to Other Hazards

A number of other hazards can contribute to the potential for wildfires or influence wildfire behavior. For example, high winds can down power lines (providing an ignition source), and/or result in areas of downed and dead trees (increasing fuel loads); high winds can also produce rapid rates of spread on active fires and increase the distance of ember transport beyond the active fire perimeter. Shaking caused by earthquakes can crack gas lines, creating a higher potential for ignition. Extreme weather conditions such as lightning can ignite fuels, resulting in wildland fires.

Increased period of dry weather can exacerbate the potential for wildfires. Drought conditions increase wildfire potential by decreasing fuel moisture. Increasing risks from wildfires in most parts of the country including the Pacific Northwest are a result of warm winters, hot and dry summers, severe drought, insect and disease infestations, years of fire suppression and growth in the wildland-urban interface.

While the natural occurrence of fire on the landscape is an important component of watershed health and may have beneficial effects in the long run (e.g., increased biodiversity) and functions as an agent of recovery (Benda et al. 2003), it can also induce dramatic and negative changes to landscape thereby influencing a number of subsequent, or cascading, natural hazards.

Physically, the heating of the soil increases the pH, and bulk density (Neil et al. 2007) and creates water-repellent soils (Debano 1981). These impacts are particularly acute for higher intensity fires. Soil- chemical alterations result via nutrient volatilization (nutrient loss to the atmosphere), as in the case of nitrogen, organic phosphorus and sulfur (Debano et al. 1998 and Klopatek 1987). Erosion and sediment mobilization are commonly referenced as prominent effects of fire on watersheds (Brown and Froemke 2010; Calkin et al. 2007; Shakesby and Doerr 2006; Brown 2000; Brown and Binkley 1994; Agee 1993). Usually, in normal unburned areas, local vegetation has a pronounced effect in reducing the surface runoff following rainfall and snowmelt. The organic ground cover consisting of tree needles, leaves, twigs and other litter on the ground soak up the water and aid in slow infiltration, preventing increased surface run-off. Intense fires burn all of the vegetation, and the organic ground cover creating hydrocarbon residue that soaks into the ground. This material fills up the pores between fine soil grains in the upper sold strata and sticks them together. Such soils become hydrophobic and are highly impervious. Consequently, in the post-fire regime, water from rainfall and snowmelt generates enhanced surface run-off. Increased amount of run-off from charred soil areas can result in flash floods and debris flows in the downstream areas. The extent and intensity of post-fire effects can range in magnitude and impact, across time and space depending on the specific watershed characteristics (Benda et al. 2003).

Debris flows in a recently burned basins, especially those with high intensity, are considered a more severe threat to water quality than sediment-laden floods (Cannon et al. 2010). The water quality in the natural drainage channels and water reservoirs is negatively impacted by debris flows in the catchment areas. A number of studies corroborate that water quality can be impaired for several years after a wildfire event. Thus, wildfire events can create financial concerns for farmers, state agencies and businesses that must meet surface water quality standards to protect for ESA-listed species. Additionally, devastated riparian areas are both difficult to reestablish and vital for anadromous fish survival.

A recent concern of high intensity wildfires is the lack of successful natural regeneration. The post-fire landscape is composed of large high-severity patches, where distance to seed source has surpassed the dispersal ability of conifers and where slow-moving, high-severity wildfires destroy the seed bank. In instances where the source is present, secondary effects to the microhabitat (soil, nutrients, water, shade and biological requirements) can prevent successful seedling establishment and survival. Drastic reduction of canopy cover increases solar radiation and temperatures, both in the atmosphere and in the soil, which results in unfavorable germination conditions, further hindering establishment and survivorship of the seedlings (Stein and Kimberling 2003, and Petrie et al., 2016). Consequently, the interior of these patches may lack conifer regeneration for decades (Savage and Mast 2005, Haire and McGarigal 2010, Roccaforte et al. 2012), potentially decreasing the ecosystem services and economic value of these forest.

Municipal watersheds are also affected significantly by wildfire events. Critical infrastructure facilities such as water recharge sites, and water intake reservoirs are located in natural watersheds. Wildfire in these areas can result in operational disruption of critical infrastructure systems resulting in serious economic and public safety consequences (Ryan and Samuels 2010). Threats to drinking water from wildfire can occur while a fire burns, from aerial application of fire retardant (Neary et al. 2005; Ryan and Samuels 2010), or in the months and years following a fire due to increased storm runoff (Shakesby and Doerr 2006), ash accumulation, and accelerated soil erosion and sedimentation (Emelko et al. 2011; Smith et al. 2010).

Wildfire also contribute to greater carbon emissions into the local environment. The Forest Foundation commissioned a 2008 report by Forest Carbon Emissions Modeling which found that combustion emissions per acre of forested land create anywhere from 12 metric tons of CO2 per acre to 46.2 metric tons of CO2 per acre. By these estimates, in 2015 alone Washington state constituted anywhere from 12,065,076 to 46,450,542 metric tons of CO2 from wildfire events. This is approximately 13-50 percent of Washingtonians' total carbon emissions per year.

Changing climatic conditions are also expected to have a significant impact on local wildfire regimes. There is a consensus among regional climate change models that the Northwestern United States is likely to become noticeably warmer with wetter winters and dryer summers. (Mote and Salathe 2010), and temperature extremes are likely to become increasingly frequent in the region (Easterling et al. 2000).

The effects of climate change on overall precipitation levels are more uncertain, and there are differences among regional climate change models (Mote and Salathe 2010). There is likewise a high level of uncertainty regarding the future occurrence of extreme precipitation events. Model described by Leung et al. (2004) show large increases in wintertime extreme rainfall events in the Cascades. In contrast, Rosenberg et al. (2010) did not find statistically significant differences in the predicted extreme precipitation events in Washington state. Various other climatic changes are also expected in Northwest forests including changes to wind patterns (Sailor et al. 2010, Zwiers et al. 1998), increases in drought severity and duration (Dale et al. 2001) and increases in atmospheric humidity levels (Flannigan et al. 2009). These deviations from climatic normal can result in a variety of ecosystem responses, many of which will have an impact on the local fire regimes. For instance, decreased fuel and soil moisture will increase flammability of the landscape (Gergel et al. 2017), as will beetle and drought-killed trees (Allen et al. 2010). In parallel, with changes in fuel moisture, dry lightning frequencies are likely to increase subsequently increasing ignition frequency (Price and Rind 1994, Flannigan 2000). The increased temperatures and reduction of periods with snow could result in a lengthening of the fire season, with an increasing number of large fires occurring during the shoulder seasons (Westerling et al. 2006). In forest ecosystems, precipitations can alter the flammability of already abundant fuels, while in rangeland systems, precipitation can control the biomass levels of often-flammable fuels (Meyn et al. 2007). The changes in fire regimes can also interact with existing hydrological and biological processes of forest systems.

Hence a cycle of the warmer wetter winters resulting in the buildup of flashy fuels, only to be ignited each summer as a result of increasingly hot dry summers, will further stress succession processes and hinder forest regeneration. Floods following these fires and their mobilizing existing soils will further limit regeneration.

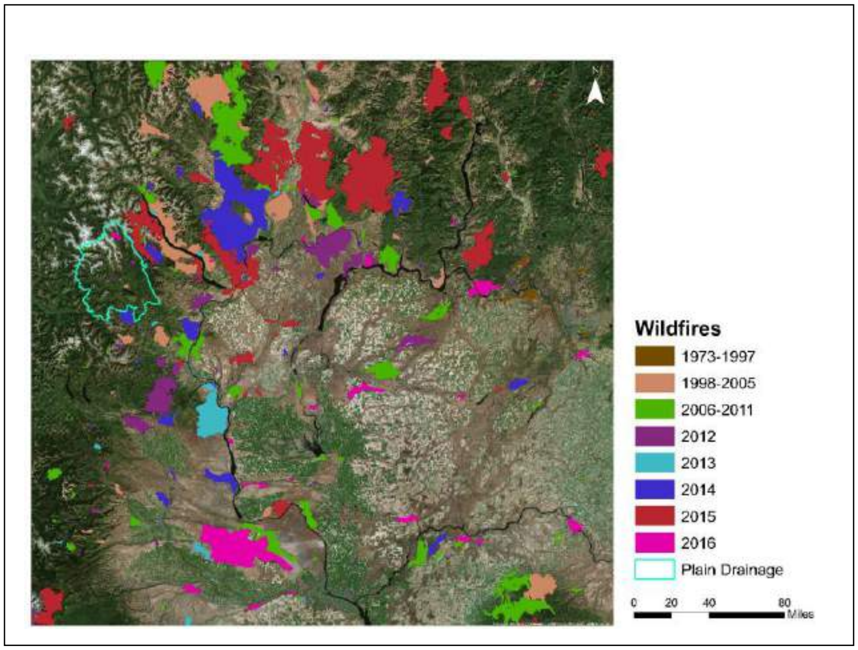

FIGURE WF 7: LARGE FIRES IN WASHINGTON STATE FROM 2000-2016. (SOURCE: NORTHWEST INTERAGENCY COORDINATION CENTER)

Wildfire Risk Assessment Methodology

The wildfire risk assessment is estimated for each of the census tracts in Washington based on two variables. First is the wildfire potential assessment derived from the U.S. Forest Service Wildfire Hazard Potential raster data (Dillon et. al. 2015). The wildfire hazard potential (WHP) map is a raster geospatial product produced by the USDA Forest Service, Fire Modeling Institute to depict the relative potential for wildfire. The 2014 version used in this analysis was built upon spatial estimates of wildfire likelihood and intensity generated in 2014 with the Large Fire Simulator (FSim) for the

Fire Program Analysis system (FPA), as well as spatial fuels and vegetation data from LANDFIRE 2010 and point locations of fire occurrence from FPA (ca. 1992 - 2012). With these datasets as inputs, an index of WHP was created for all of the conterminous United States at a 270-meter resolution. The five ranked WHP classes of very low (1), low (2), moderate (3), high (4) and very high (5) were utilized in his analysis. The areas mapped with higher WHP values represent fuels with a higher probability of experiencing torching, crowning and other forms of extreme fire behavior under conducive weather conditions, based primarily on 2010 landscape conditions.

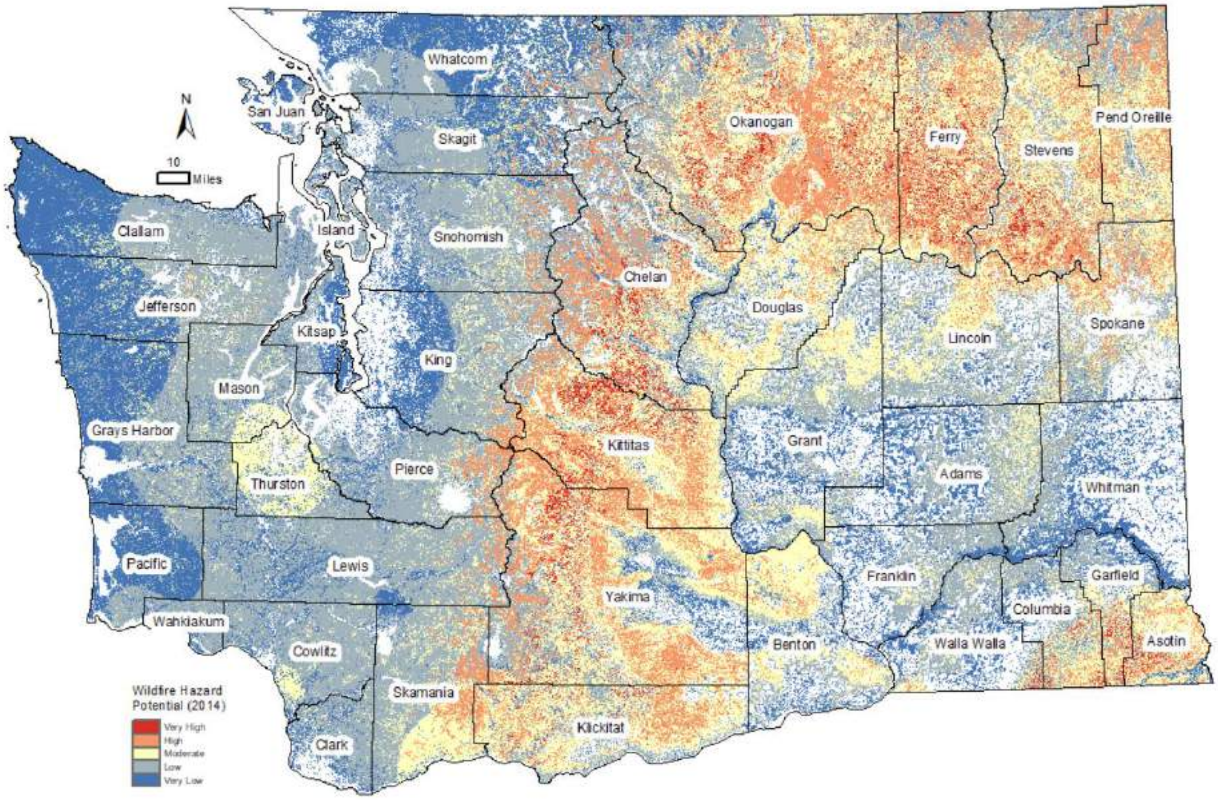

Figure WF 8: Wildfire Hazard Potential - 2014 (Source: USDA Forest Service)

The second is the Wildlife Urban Interface (WUI) communities as identified by Washington Department of Natural Resources (DNR). WUI is defined as the area where structures and other human development meet or intermingle with undeveloped wildland (Radeloff et. al. 2005). The expansion of the WUI in recent decades has significant implications for wildfire management and impact. The WUI creates an environment in which fire can move readily between structural and vegetation fuels. Its expansion in recent decades has increased the likelihood that wildfires will threaten structures and people. This data is based on the current National Fire Protection Association (NFPA 299) risk assessment and includes one or several communities with similar wildfire risks. The communities are given four hazard ratings – low, moderate, high and extreme.

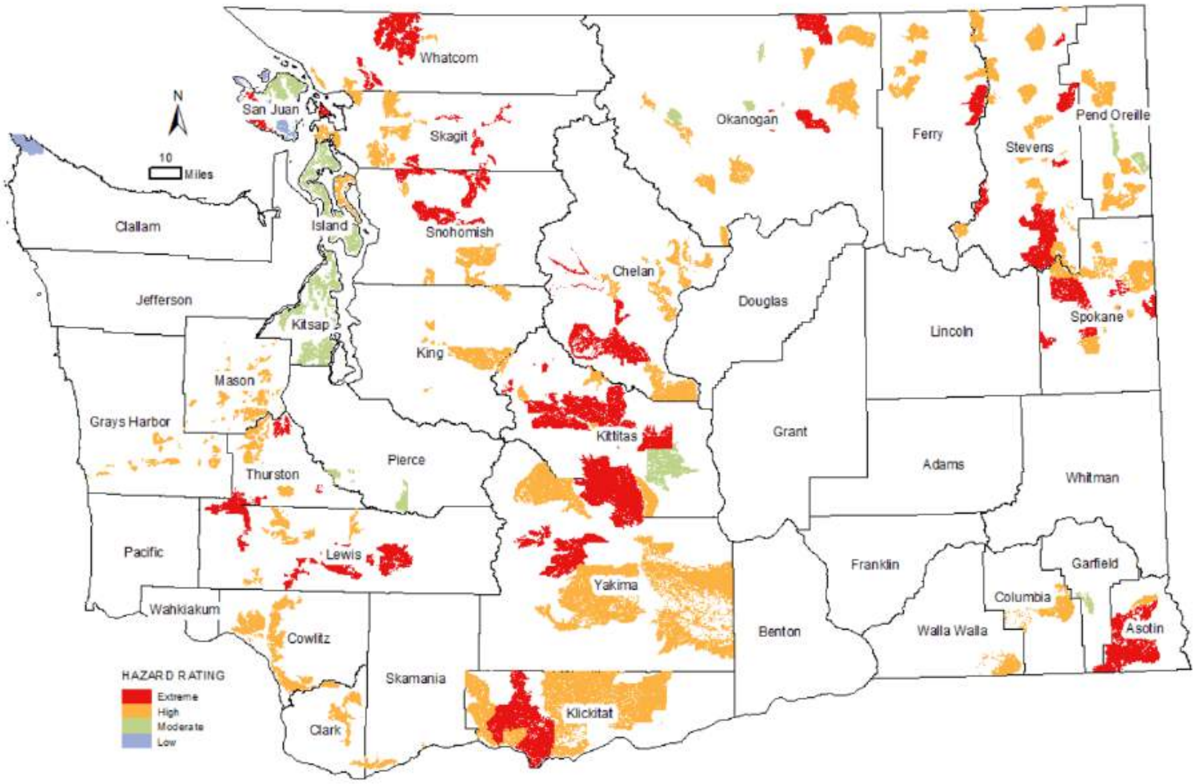

FIGURE WF 9: RATING OF WILDFIRE HAZARD IN WUI (SOURCE: DNR)

The wildfire hazard potential and community hazard ratings were combined to create the wildfire hazard layer. Community hazard ratings were recategorized on a five-point scale, low – 1, moderate – 3, High – 4 and Extreme – 5. The two ratings were combined through spatial raster overlay analysis to generate the wildfire hazard score, which is the average of the two hazard rankings.

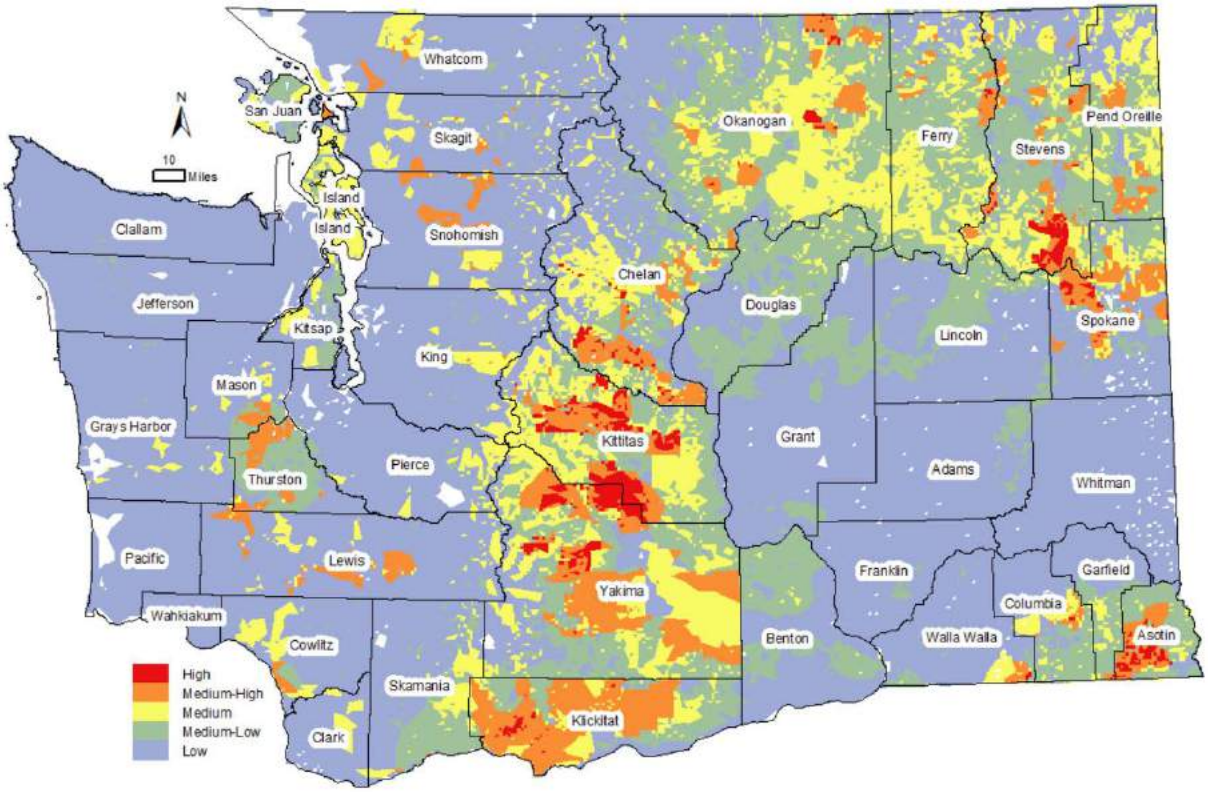

FIGURE WF 10: DISTRIBUTION OF WILDFIRE RISK

Area Exposure

The wildfire hazard area map was overlaid with the county map to estimate the percentage area exposed to wildfire hazard in each county. A majority of the State (59 percent) is ranked low for wildfire hazard exposure. These areas primarily correspond to the very low and low designated for wildfire hazard potential characterized by USGS. In comparison, 21 percent of the total land area of the state is estimated to be at medium or higher level of risk from wildfires. Less than two percent of the area is ranked high for wildfire exposure, and another seven percent is ranked medium-high for wildfire exposure. Most of these areas include WUI regions with high or extreme hazard ratings.

In Kittitas County, almost 12 percent of the areas is ranked high for wildfire exposure. Another, 16 percent of the county area is ranked medium-high. Overall, more than 60 percent of the area in Kittitas County is ranked medium or higher for wildfire hazard. In Asotin County, almost 10 percent of the county area is ranked high, and 29 percent is ranked medium-high for wildfire hazard exposure. In Yakima County, almost 5 percent of the area is ranked high for wildfire hazard, and almost 22 percent is ranked medium-high. In Island County, 78 percent of the area is ranked at medium for wildfire hazard exposure. This is primarily driven by WUI moderate hazard rating. In Klickitat County, almost 50 percent of the land area is ranked medium-high or higher for wildfire hazard exposure. In Yakima, Thurston and Spokane Counties, approximately 20 percent area is ranked medium-high for wildfire hazard.

The wildfire hazard exposure in concentrated in the Central Ecological Region, and Northern Counties of the Eastern Ecological Region. Pend Oreille, Ferry, Stevens, Chelan and Okanogan Counties have 35-40 percent of the area ranked at medium or higher from wildfire exposure.

Percentage of County Land Area with Wildfire Hazard Exposure

County	Percent County Area in Wildfire Hazard Zone				
	Low	Medium Low	Medium	Medium High	High
Adams	93.50	6.50	0.00	0.00	0.00
Asotin	7.71	48.22	5.76	29.28	9.03
Benton	56.38	42.86	0.61	0.14	0.00
Chelan	43.24	19.34	24.15	11.58	1.69
Clallam	99.60	0.40	0.00	0.00	0.00
Clark	86.59	0.00	13.41	0.00	0.00
Columbia	52.38	28.62	15.02	3.76	0.21
Cowlitz	79.89	3.44	14.03	2.64	0.00
Douglas	35.46	61.46	3.05	0.03	0.00
Ferry	11.73	49.43	34.11	4.50	0.22
Franklin	97.77	2.23	0.00	0.00	0.00
Garfield	64.22	27.65	7.30	0.69	0.14
Grant	82.39	17.57	0.03	0.00	0.00
Grays Harbor	96.31	0.81	2.87	0.00	0.00
Island	7.63	14.72	77.65	0.00	0.00
Jefferson	99.10	0.87	0.03	0.00	0.00
King	88.63	1.26	9.94	0.17	0.00
Kitsap	55.59	23.75	20.66	0.00	0.00
Kittitas	8.66	30.81	33.31	15.83	11.39
Klickitat	11.83	23.15	15.73	47.85	1.44
Lewis	84.63	0.84	6.31	8.23	0.00
Lincoln	70.81	27.76	1.41	0.00	0.01
Mason	82.87	7.72	4.72	4.68	0.00
Okanogan	26.20	38.55	28.54	5.74	0.96
Pacific	99.94	0.06	0.00	0.00	0.00
Pend Oreille	19.48	37.73	32.14	10.65	0.00
Pierce	88.36	3.53	8.11	0.00	0.00
San Juan	31.44	40.15	28.41	0.00	0.00
Skagit	82.98	1.82	12.21	2.99	0.00
Skamania	62.77	25.65	11.41	0.17	0.00
Snohomish	80.85	1.24	7.56	10.35	0.00
Spokane	49.72	17.85	11.31	19.20	1.92
Stevens	16.90	45.65	22.43	11.08	3.94
Thurston	26.47	52.01	1.15	20.38	0.00
Wahkiakum	100.00	0.00	0.00	0.00	0.00
Walla Walla	88.29	4.68	4.58	2.14	0.30
Whatcom	87.50	1.33	9.14	2.04	0.00
Whitman	99.47	0.53	0.00	0.00	0.00

Percentage of County Land Area with Wildfire Hazard Exposure					
County	Percent County Area in Wildfire Hazard Zone				
	Low	Medium Low	Medium	Medium High	High
Yakima	16.53	28.31	29.33	21.17	4.66
Washington State	58.68	19.98	13.21	6.96	1.18

Population Exposure

Population exposure to wildfires was estimated by overlaying the wildfire hazard layer over the 2011 developed areas derived from the land cover database. The 2017 estimated population for all census tracts was allocated to respective urban areas and the overlap with wildfire exposure was estimated using spatial analysis in Geographic Information System (GIS). While less than 2 percent of the state area is exposed to wildfires (medium or higher exposure), the population exposure is estimated to be 8 percent of the total estimated state population. More than 80percent of the county population in Pend Oreille resides in areas with medium or higher exposure to wildfires. In Thurston County, 70 percent of the county population, approximately 200,000 persons, is located in areas at medium or higher exposure to wildfire. In three counties – Okanogan, San Juan, and Island, 31-33 percent of the county population is located in areas ranked medium or higher for wildfire exposure. Approximately 25 percent of the county population in Klickitat, Skamania and Kitsap Counties is located in areas with medium or higher wildfire exposure. In Mason, Kittitas and Stevens Counties, about 20 percent of the population resides in areas with medium or higher wildfire exposure. Asotin and Spokane Counties also have approximately 12 percent of the county population residing in areas with medium or higher wildfire risk.

Population Exposure to Wildfires			
County	Total Population (2017 Estimates)	Percentage of Total State Population	Estimated Population Exposure to Wildfires Ranked Medium or Higher (in % values)
Adams	19870	0.27	0.00
Asotin	22290	0.30	12.64
Benton	193500	2.65	5.60
Chelan	76830	1.05	6.46
Clallam	74240	1.02	0.00
Clark	471000	6.44	0.00
Columbia	4100	0.06	0.00
Cowlitz	105900	1.45	1.28
Douglas	41420	0.57	7.23
Ferry	7740	0.11	0.00
Franklin	90330	1.24	0.00
Garfield	2200	0.03	0.00

Population Exposure to Wildfires			
County	Total Population (2017 Estimates)	Percentage of Total State Population	Estimated Population Exposure to Wildfires Ranked Medium or Higher (in % values)
Grant	95630	1.31	1.23
Grays Harbor	72970	1.00	0.00
Island	82790	1.13	31.67
Jefferson	31360	0.43	0.00
King	2153700	29.46	0.03
Kitsap	264300	3.62	24.27
Kittitas	44730	0.61	19.68
Klickitat	21660	0.30	26.18
Lewis	77440	1.06	0.21
Lincoln	10700	0.15	0.00
Mason	63190	0.86	19.95
Okanogan	42110	0.58	33.57
Pacific	21250	0.29	0.00
Pend Oreille	13370	0.18	83.58
Pierce	859400	11.76	0.52
San Juan	16510	0.23	33.49
Skagit	124100	1.70	0.00
Skamania	11690	0.16	25.73
Snohomish	789400	10.80	0.00
Spokane	499800	6.84	12.21
Stevens	44510	0.61	18.42
Thurston	276900	3.79	70.33
Wahkiakum	4030	0.06	0.00
Walla Walla	61400	0.84	0.39
Whatcom	216300	2.96	0.00
Whitman	48640	0.67	0.00
Yakima	253000	3.46	2.52
Washington State	7310300	100.00	8.17

Vulnerable Population Exposure

The social vulnerability index was created for each of the census tracts using American Community Survey (ACS) 2011-2016 5-year data. Social vulnerability data was first overlaid with developed areas extracted from the 2011 land cover database. Tract level social vulnerability estimates were assigned to respective developed areas in each of the tracts. This data was then overlaid with wildfire hazard layer to identify socially vulnerable developed areas that overlap with medium or higher wildfire exposure.

Overall, less than two percent of the total state population is both, ranked medium or higher on social vulnerability index and resides in areas with medium or higher exposure to wildfire. In Okanogan County, 13 percent of the county population is both ranked medium or higher on social vulnerability and is located in areas with medium or higher wildfire exposure. In Mason County, approximately 3600 people (~6 percent of county population) residing in areas with medium or higher wildfire exposure are also ranked medium or higher on social vulnerability. In Douglas County, 3.4 percent of the county population is located in areas with medium or higher wildfire exposure and is also ranked medium or higher on social vulnerability Index. In Yakima, Spokane, Benton and Thurston Counties less than 1 percent of the county population is both ranked medium or higher on social vulnerability and is located in areas with medium or higher wildfire exposure.

Vulnerable Population Exposure to Wildfires

County	Population (2017 Estimates)	Vulnerable Population in Areas with Medium or Higher Wildfire Exposure	
		Vulnerable Population	% of Total County Population
Adams	0	0	0.00
Asotin	2817	0	0.00
Benton	10829	<10	0.00
Chelan	4962	0	0.00
Clallam	0	0	0.00
Clark	0	0	0.00
Columbia	0	0	0.00
Cowlitz	1357	0	0.00
Douglas	2996	1403	3.39
Ferry	0	0	0.00
Franklin	0	0	0.00
Garfield	0	0	0.00
Grant	1172	108	0.11
Grays Harbor	0	0	0.00
Island	26218	0	0.00
Jefferson	0	0	0.00
King	582	0	0.00
Kitsap	64137	0	0.00
Kittitas	8805	0	0.00
Klickitat	5671	0	0.00
Lewis	163	0	0.00
Lincoln	0	0	0.00
Mason	12609	3609	5.71
Okanogan	14138	5605	13.31

Vulnerable Population Exposure to Wildfires			
County	Population (2017 Estimates)	Vulnerable Population in Areas with Medium or Higher Wildfire Exposure	
		Vulnerable Population	% of Total County Population
Pacific	0	0	0.00
Pend Oreille	11175	0	0.00
Pierce	4512	0	0.00
San Juan	5529	0	0.00
Skagit	0	0	0.00
Skamania	3007	0	0.00
Snohomish	0	0	0.00
Spokane	61027	2284	0.46
Stevens	8199	355	0.80
Thurston	194749	1853	0.67
Wahkiakum	0	0	0.00
Walla Walla	240	0	0.00
Whatcom	0	0	0.00
Whitman	0	0	0.00
Yakima	6378	2348	0.93
Washington State	451273	102471	1.40

Built Environment Exposure

The built environment exposure to wildfire hazard is calculated using the general building stock data (2014) provided by FEMA that contains the building values for all structures in the census tracts. General building stock values used in this analysis are the total structure value of all buildings (except agricultural) in each census tract in 2014 dollars. Building values for all occupancy types were summed for each census tract using only structure values (not content values) and assigned to the developed areas within each tract. These maps were then overlaid on the wildfire hazard layer to estimate the general building stock value within hazard exposure areas. Individual tract level estimates were aggregated to create the county level estimates.

Overall, less than 3 percent of the general building stock of the state is located in areas with medium or higher wildfire exposure. Thurston County has highest value (~$690 million) of general building stock value located in areas ranked medium or higher for wildfire exposure. In Kitsap County approximately $420 million and in Spokane County approximately $390 million of general building stock is located in areas with medium or higher wildfire exposure. Cumulatively, the top three counties with highest value of building stock in areas with medium or higher wildfire risk represent about 2 percent of the total state general building stock. In Pend Oreille County, 84 percent of the county general building stock is located in areas with medium or higher wildfire exposure. Klickitat County with 65 percent of county area with medium or higher wildfire hazard exposure, is estimated to have 26 percent (~$117 thousand) of the county general building stock in these wildfire hazard areas.

Built Environment Exposure to Wildfires			
County	Total Value of General Building Stock (2014)	Exposed to Wildfires (Medium or higher)	
		Total Value of General Building Stock (2014)	Percent of Total County General Building Stock (2014)
Adams	$253,615	$0	0.00
Asotin	$1,061,235	$13,414,052	12.64
Benton	$6,529,565	$36,543,490	5.60
Chelan	$1,573,417	$10,160,978	6.46
Clallam	$2,427,219	$0	0.00
Clark	$32,074,170	$0	0.00
Columbia	$533	$0	0.00
Cowlitz	$4,992,730	$6,399,687	1.28
Douglas	$1,211,949	$8,767,113	7.23
Ferry	$1,521	$0	0.00
Franklin	$1,867,499	$0	0.00
Garfield	$437	$0	0.00
Grant	$583,022	$714,550	1.23
Grays Harbor	$1,162,104	$0	0.00
Island	$2,895,464	$91,692,823	31.67
Jefferson	$1,137,144	$0	0.00
King	$362,698,022	$9,800,951	0.03
Kitsap	$17,267,166	$419,017,016	24.27
Kittitas	$530,126	$10,435,336	19.68
Klickitat	$4,479	$117,278	26.18
Lewis	$1,402,914	$294,837	0.21
Lincoln	$87,198	$0	0.00
Mason	$608,531	$12,142,625	19.95
Okanogan	$59,252	$1,989,261	33.57
Pacific	$125,715	$0	0.00
Pend Oreille	$8,310	$694,549	83.58
Pierce	$62,547,883	$32,835,688	0.52
San Juan	$225,856	$7,563,687	33.49
Skagit	$5,389,339	$0	0.00
Skamania	$17,391	$447,419	25.73
Snohomish	$52,406,666	$0	0.00
Spokane	$31,281,088	$381,950,941	12.21
Stevens	$325,218	$5,991,044	18.42
Thurston	$9,798,392	$689,139,170	70.33

Built Environment Exposure to Wildfires			
County	Total Value of General Building Stock (2014)	**Exposed to Wildfires (Medium or higher)**	
		Total Value of General Building Stock (2014)	Percent of Total County General Building Stock (2014)
Wahkiakum	$1,649	$0	0.00
Walla Walla	$3,061,065	$1,197,929	0.39
Whatcom	$15,241,051	$0	0.00
Whitman	$1,385,430	$0	0.00
Yakima	$7,986,979	$20,135,032	2.52
Washington State	$630,231,344	$13,543,671,583	21.49

Critical Infrastructure Exposure

Critical infrastructure facilities that lie within the wildfire hazard areas are likely to be directly impacted by landslide events. While the nature and degree of impact will largely depend on the size of the wildfire characteristics and the physical details of the facility, location within the medium or higher wildfire hazard exposure areas can enable prioritization of site specific hazard mitigation studies. Location of 12 critical infrastructure facilities including airports (23), dams (268), education facilities (5331), electric substations (1390), hospitals (147), power plants (146), public transit stations (60), railroad bridges (1619) and railway stations (317) were derived from the Homeland Security Foundation Level Database (HIFLD). This data was overlaid with the wildfire hazard exposure layer to identify facilities located in wildfire hazard areas. This analysis refers to point data and not critical infrastructure represented by a line such as roads and rail corridors. These networks will also be impacted by wildfire but due to data limitation they have not been included in this analysis.

Spatial analysis of this dataset reveals that only 13 percent of the critical infrastructure facilities in the state are located in areas with medium or higher wildfire exposure. Yakima County has the maximum number of critical infrastructure facilities (280) located in areas with medium or higher landslide exposure. In Spokane County, 272 of the 933 critical infrastructure facilities are located in areas with medium or higher wildfire exposure. In Island County, 67 percent of the critical infrastructure facilities are located in areas with medium wildfire exposure. In Kittitas and Klickitat Counties, approximately 50 percent of the critical infrastructure facilities are located in areas with medium or higher wildfire exposure. While this analysis identifies critical facilities likely to be at medium or higher risk from wildfires, it is important to note that specific risk to each facility results from the combination of the event characteristics (which are difficult to predict) and the site-level facility characteristics.

This analysis of Critical Facilities does not address the indirect vulnerabilities due to road segments or losses resulting from interrupted access.

Critical Infrastructure Exposure

County	Number of Critical Infrastructure Facilities	In Wildfire Exposure Areas	
		Number of Critical Infrastructure Facilities	Percent of Critical Infrastructure Facilities
Adams	206	0	0.00
Asotin	81	17	20.99
Benton	664	0	0.00
Chelan	507	118	23.27
Clallam	273	0	0.00
Clark	490	38	7.76
Columbia	88	30	34.09
Cowlitz	474	122	25.74
Douglas	290	5	1.72
Ferry	83	18	21.69
Franklin	270	0	0.00
Garfield	89	38	42.70
Grant	501	7	1.40
Grays Harbor	377	9	2.39
Island	104	70	67.31
Jefferson	197	0	0.00
King	2761	53	1.92
Kitsap	451	40	8.87
Kittitas	303	160	52.81
Klickitat	322	158	49.07
Lewis	374	53	14.17
Lincoln	237	1	0.42
Mason	152	11	7.24
Okanogan	359	128	35.65
Pacific	152	0	0.00
Pend Oreille	69	17	24.64
Pierce	1130	8	0.71
San Juan	98	23	23.47
Skagit	474	162	34.18
Skamania	145	8	5.52
Snohomish	787	51	6.48
Spokane	933	272	29.15
Stevens	211	51	24.17
Thurston	462	44	9.52
Wahkiakum	17	0	0.00
Walla Walla	273	3	1.10
Whatcom	613	61	9.95
Whitman	409	0	0.00

Washington State	16027	2056	12.83

State Operations and Facilities Exposure

The list of state owned (9415) and leased facilities (1039) was obtained from 2017 Facilities Inventory System Report produced by Office of Financial Management (detailed list included in Appendix I-2). These facilities were geo-located based on the addresses provided in the facilities inventory report and then overlaid with wildfire hazard layer.

The spatial analysis reveals that 18 percent of the state-owned facilities are located in areas with medium or higher wildfire exposure. King County has the maximum number (182) of facilities located in areas with medium or higher wildfire exposure. Pierce County has 144 of its 864 state-owned facilities located in medium or higher wildfire exposure areas. In San Juan and Island Counties, approximately 27 percent of the state-owned facilities in the county are located in areas ranked medium or higher for wildfire exposure. In these counties, most of these facilities are in areas ranked medium. In all counties with the exception of Ferry County, at least 10 percent of the state-owned facilities are locate in areas with medium or higher wildfire exposure. In Ferry County, only three of the 32 state-owned facilities are located in areas with medium or higher wildfire exposure.

Overall, less than 1 percent of the state-leased facilities are located in areas with medium or higher wildfire hazard exposure. Spokane County has the maximum number (10) of leased facilities in wildfire threatened areas in the state. As such, wildfire does not represent a significant risk to the state-leased properties.

State Owned and Leased Facilities Exposure

County	State Owned Facilities	State Leased Facilities	In areas Exposed to Wildfire			
			State Owned Facilities	Percent of State Owned Facilities	State Leased Facilities	Percent of State Leased Facilities
Adams	64	1	9	14.06	0	0.00
Asotin	90	6	17	18.89	0	0.00
Benton	159	30	17	10.69	0	0.00
Chelan	192	22	27	14.06	7	3.65
Clallam	183	12	27	14.75	0	0.00
Clark	229	23	47	20.52	0	0.00
Columbia	75	1	14	18.67	1	1.33

State Owned and Leased Facilities Exposure

County	State Owned Facilities	State Leased Facilities	In areas Exposed to Wildfire			
			State Owned Facilities	Percent of State Owned Facilities	State Leased Facilities	Percent of State Leased Facilities
Cowlitz	128	18	23	17.97	1	0.78
Douglas	42	10	7	16.67	0	0.00
Ferry	32	3	3	9.38	3	9.38
Franklin	160	9	19	11.88	0	0.00
Garfield	21	0	4	19.05	0	0.00
Grant	252	15	46	18.25	0	0.00
Grays Harbor	224	13	44	19.64	0	0.00
Island	269	6	71	26.39	2	0.74
Jefferson	394	5	68	17.26	0	0.00
King	1120	226	182	16.25	0	0.00
Kitsap	269	15	44	16.36	0	0.00
Kittitas	348	11	57	16.38	0	0.00
Klickitat	110	10	22	20.00	0	0.00
Lewis	163	13	27	16.56	0	0.00
Lincoln	58	0	12	20.69		0.00
Mason	244	7	47	19.26	1	0.41
Okanogan	179	10	27	15.08	2	1.12
Pacific	233	6	39	16.74	0	0.00
Pend Oreille	18	5	4	22.22	0	0.00
Pierce	865	54	144	16.65	0	0.00
San Juan	282	5	78	27.66	3	1.06
Skagit	286	15	52	18.18	0	0.00
Skamania	64	2	11	17.19	0	0.00
Snohomish	270	71	33	12.22	0	0.00
Spokane	571	121	100	17.51	10	1.75
Stevens	65	7	15	23.08	0	0.00
Thurston	431	166	88	20.42	0	0.00
Wahkiakum	22	0	4	18.18	0	0.00
Walla Walla	159	11	29	18.24	0	0.00
Whatcom	283	32	51	18.02	0	0.00
Whitman	566	9	104	18.37	0	0.00
Yakima	294	61	45	15.31	9	3.06
Washington State	9415	1031	1658	17.61	39	0.41

First Responder Facilities Exposure

Locations of fire stations, law enforcement buildings, and emergency medical stations in the state were identified from the Homeland Security Foundation Level Database (HIFLD). Using ESRI ArcMap geocoding services 1,268 fire stations, 332 law enforcement agencies and 1,162 EMS stations (including those co-located with fire stations) were located on the state map. It is estimated that 18 percent of the fire stations, 6 percent of the law enforcement buildings, and 17 percent of the EMS facilities are located in areas with medium or higher wildfire exposure. In Yakima County almost 50 percent of all fire stations (28), law enforcement buildings (8) and EMS facilities (27) are located in areas with medium or higher exposure to wildfires. In Island County, nine of the 10 fire stations, one of the four law enforcement buildings, and eight of the nine EMS facilities are located in areas with medium wildfire hazard exposure. In Kittitas County, 67 percent of the fire stations (21), 33 percent of the law enforcement buildings (one), and 89 percent of the EMS facilities (eight) are located in areas with medium or higher wildfire exposure. In King County, that has the largest number of each of these facilities, only three fire stations, and three EMS facilities are located in areas with medium or higher exposure to wildfires. None of the law enforcement buildings are exposed to wildfire risk in King County.

As mentioned above, wildfire suppression efforts need to be directed to protecting forest generated ecosystem services including flood prevention, harvesting, sports and recreation, clean air and water. This can only occur in communities by adopting Fire Adaptive Community and FireWise practices, enable suppression effort to be direct at protecting forest generating resources.

First Responder Facilities Exposure to Wildfires

County	Fire Station			Law Enforcement			EMS		
	Total Number of Facilities	In areas Exposed to Landslide		Total Number of Facilities	In areas Exposed to Landslides		Total Number of Facilities	In areas Exposed to Landslides	
		Number of facilities	Percent Facilities		Number of facilities	Percent Facilities		Number of facilities	Percent Facilities
Adams	11	0	0.00	4	0	0.00	5	0	0.00
Asotin	3	0	0.00	4	0	0.00	2	0	0.00
Benton	29	0	0.00	7	0	0.00	27	0	0.00
Chelan	30	12	40.00	3	0	0.00	21	7	33.33
Clallam	22	0	0.00	5	0	0.00	24	0	0.00
Clark	40	3	7.50	13	0	0.00	40	3	7.50
Columbia	3	0	0.00	1	0	0.00	2	0	0.00
Cowlitz	25	7	28.00	8	1	12.50	17	6	35.29
Douglas	12	0	0.00	3	0	0.00	8	0	0.00
Ferry	12	6	50.00	3	2	66.67	5	2	40.00
Franklin	20	0	0.00	7	0	0.00	15	0	0.00
Garfield	2	0	0.00	1	0	0.00	1	0	0.00

First Responder Facilities Exposure to Wildfires

County	Fire Station			Law Enforcement			EMS		
	Total Number of Facilities	In areas Exposed to Landslide		Total Number of Facilities	In areas Exposed to Landslides		Total Number of Facilities	In areas Exposed to Landslides	
		Number of facilities	Percent Facilities		Number of facilities	Percent Facilities		Number of facilities	Percent Facilities
Grant	50	1	2.00	15	1	6.67	28	1	3.57
Grays Harbor	32	1	3.13	9	0	0.00	20	0	0.00
Island	10	9	90.00	4	1	25.00	9	8	88.89
Jefferson	12	0	0.00	4	0	0.00	13	0	0.00
King	159	3	1.89	60	0	0.00	161	3	1.86
Kitsap	47	10	21.28	6	0	0.00	49	10	20.41
Kittitas	33	21	63.64	6	2	33.33	33	20	60.61
Klickitat	36	22	61.11	3	0	0.00	25	13	52.00
Lewis	51	9	17.65	12	0	0.00	50	7	14.00
Lincoln	10	0	0.00	4	0	0.00	9	0	0.00
Mason	46	16	34.78	3	0	0.00	47	16	34.04
Okanogan	27	12	44.44	7	2	28.57	17	7	41.18
Pacific	16	0	0.00	5	0	0.00	10	0	0.00
Pend Oreille	18	8	44.44	1	0	0.00	16	6	37.50
Pierce	99	2	2.02	29	0	0.00	101	2	1.98
San Juan	4	1	25.00	1	1	100.00	5	2	40.00
Skagit	39	12	30.77	6	0	0.00	40	12	30.00
Skamania	3	1	33.33	2	0	0.00	3	1	33.33
Snohomish	74	4	5.41	23	0	0.00	73	4	5.48
Spokane	52	9	17.31	10	0	0.00	50	10	20.00
Stevens	34	14	41.18	6	1	16.67	27	12	44.44
Thurston	47	15	31.91	17	2	11.76	55	13	23.64
Wahkiakum	9	0	0.00	1	0	0.00	5	0	0.00
Walla Walla	21	1	4.76	3	0	0.00	20	1	5.00
Whatcom	50	8	16.00	10	0	0.00	54	8	14.81
Whitman	24	0	0.00	8	0	0.00	22	0	0.00
Yakima	56	28	50.00	18	8	44.44	53	27	50.94
Washington State	1268	235	18.53	332	21	6.33	1162	201	17.30

Washington State Risk Index for Wildfire (WaSRI-WF)

The wildfire risk index (WaSRI-WF) for each county is estimated as the average of the standardized rank of wildfire exposure assessment for population, vulnerable populations, built environment, critical infrastructure facilities, state facilities and first responder facilities. The individual exposure assessment values were categorized into 5 classes (1: Low, 2: Medium-Low, 3: Medium, 4: Medium-High, and 5: High) using z-score transformation (standard deviations from the mean).

Classification Schema for Standardized Exposure Assessment Values	
Standard Deviation	Classification Rank
>1	High (5)
0.50 to 1.0	Medium-High (4)
0.5 to -0.5	Medium (3)
-0.5 to -1	Medium-Low (2)
< -1.0	Low (1)

The wildfire risk index (WaSRI-WF) is the mean of these individual exposure rankings. While similar assessments were also done for economic consequences and risk to environment (described in the next sections), these specific rankings were not included in the estimation of the landslide risk index. Economic consequence rankings were not included because of data quality limitations. Economic consequences estimates are based on overall county data. Including them in the index is likely to result in biased estimation of landslide risk. The natural environment assessment includes a limited number of environmental resources. Each natural hazard is associated with specific effects on the natural environment and therefore adoption of a common evaluation approach across all hazard types for environmental impacts is not appropriate.

The statistical analysis of wildfire exposure assessments reveals that six counties – Island, Klickitat, Okanogan, Pend Oreille, San Juan and Stevens are at the highest risk from wildfires. Among these, the Island county is estimated to have only medium wildfire hazard exposure. All of these counties, except for Stevens County, have high proportion of residents (ranked high) located in areas exposed to medium or higher wildfire hazard. While the proportion of built environment at risk from wildfires is consistently high among these counties, exposure of vulnerable population varies greatly. Two counties, Okanogan ad Stevens are ranked high for vulnerable population exposure to wildfires, the other three are ranked only at medium.

Ten counties – Asotin, Chelan, Ferry, Kitsap, Kittitas, Mason, Skamania, Spokane, Thurston and Yakima are ranked at medium-high for wildfire. While the exposure assessment across all variables predominantly ranges from medium to medium-high for most of the variables, high vulnerable population exposure is estimated in Mason, Spokane, Thurston and Yakima Counties. Wildfire risks to the built environment are consistently ranked medium-low across the majority of the counties. This indicated that most of the development activities are located at a relatively safe distance from the areas exposed to wildfire risks. First responder facilities are also ranked at low for a number of counties (14) indicating that these facilities are located at a safe distance from known wildfire risk areas.

Wildfire Risk Index (WaSRI WF) and Constituent Landslide Exposure Ranks for Each County

County	Area	Population	Vulnerable Population	Built Environment	Critical Infrastructure	State Facilities	First Responder Facilities	Wildfire Risk Index (WaSRI WF)
Adams	Low	Medium-Low	Medium	Medium-Low	Low	Low	Low	LOW
Asotin	High	Medium-High	Medium	Medium-High	Medium-High	Medium-High	Low	MEDIUM-HIGH
Benton	Medium-Low	Medium-High	Medium	Medium-High	Low	Low	Low	MEDIUM-LOW
Chelan	Medium-High	Medium-High	Medium	Medium-High	Medium-High	Medium-Low	Medium-High	MEDIUM-HIGH
Clallam	Low	Medium-Low	Medium	Medium-Low	Low	Low	Low	LOW
Clark	Medium	Medium-Low	Medium	Medium-Low	Medium	High	Medium	MEDIUM
Columbia	Medium-High	Medium-Low	Medium	Medium-Low	High	High	Low	MEDIUM
Cowlitz	Medium	Medium	Medium	Medium	Medium-High	Medium	Medium-High	MEDIUM
Douglas	Medium-Low	Medium-High	High	Medium-High	Medium-Low	Low	Low	MEDIUM-LOW
Ferry	High	Medium-Low	Medium	Medium-Low	Medium-High	Medium	High	MEDIUM-HIGH
Franklin	Low	Medium-Low	Medium	Medium-Low	Low	Low	Low	LOW
Garfield	Medium-Low	Medium-Low	Medium	Medium-Low	High	High	Low	MEDIUM
Grant	Low	Medium	High	Medium	Medium-Low	Medium-High	Medium	MEDIUM
Grays Harbor	Medium-Low	Medium-Low	Medium	Medium-Low	Medium-Low	Medium-High	Medium-Low	MEDIUM-LOW
Island	High	High	Medium	High	High	High	High	HIGH
Jefferson	Low	Medium-Low	Medium	Medium-Low	Low	Medium	Low	LOW
King	Medium	Medium	Medium	Medium	Medium-Low	Low	Medium-Low	MEDIUM-LOW

Wildfire Risk Index (WaSRI WF) and Constituent Landslide Exposure Ranks for Each County

County	Area	Population	Vulnerable Population	Built Environment	Critical Infrastructure	State Facilities	First Responder Facilities	Wildfire Risk Index (WaSRI WF)
Kitsap	Medium-High	High	Medium	High	Medium	Medium-Low	Medium-High	MEDIUM-HIGH
Kittitas	High	Medium-High	Medium	Medium-High	High	Medium-Low	High	MEDIUM-HIGH
Klickitat	High	High	Medium	High	High	Medium-High	High	HIGH
Lewis	Medium	Medium	Medium	Medium	Medium	Medium-Low	Medium	MEDIUM
Lincoln	Medium-Low	Medium-Low	Medium	Medium-Low	Medium-Low	High	Low	MEDIUM-LOW
Mason	Medium	Medium-High	High	Medium-High	Medium	High	Medium-High	MEDIUM-HIGH
Okanogan	Medium-High	High	High	High	High	Medium-Low	High	HIGH
Pacific	Low	Medium-Low	Medium	Medium-Low	Low	Medium	Low	LOW
Pend Oreille	High	High	Medium	High	Medium-High	Medium-High	Medium-High	HIGH
Pierce	Medium-Low	Medium	Medium	Medium	Medium-Low	Medium-Low	Medium	MEDIUM-LOW
San Juan	Medium-High	High	Medium	High	Medium-High	High	Medium-High	HIGH
Skagit	Medium	Medium-Low	Medium	Medium-Low	High	Medium-High	Medium-High	MEDIUM
Skamania	Medium	High	Medium	High	Medium	Medium	Medium-High	MEDIUM-HIGH
Snohomish	Medium-High	Medium-Low	Medium	Medium-Low	Medium	Low	Medium	MEDIUM-LOW
Spokane	Medium-High	Medium-High	High	Medium-High	Medium-High	Medium	Medium	MEDIUM-HIGH
Stevens	High	Medium-High	High	Medium-High	Medium-High	High	High	HIGH

Wildfire Risk Index (WaSRI WF) and Constituent Landslide Exposure Ranks for Each County

County	Area	Population	Vulnerable Population	Built Environment	Critical Infrastructure	State Facilities	First Responder Facilities	Wildfire Risk Index (WaSRI WF)
Thurston	Medium-High	High	High	High	Medium	Medium-Low	Medium-High	MEDIUM-HIGH
Wahkiakum	Low	Medium-Low	Medium	Medium-Low	Low	Medium-High	Low	LOW
Walla Walla	Medium-Low	Medium	Medium	Medium	Medium-Low	Medium	Medium	MEDIUM-LOW
Whatcom	Medium	Medium-Low	Medium	Medium-Low	Medium	Medium	Medium	MEDIUM-LOW
Whitman	Low	Medium-Low	Medium	Medium-Low	Low	Medium-High	Low	LOW
Yakima	High	Medium	High	Medium	High	Medium-Low	High	MEDIUM-HIGH

Economic Consequences

The economic activity data was derived from National Association of Counties. This dataset provides the county level estimates of Gross Domestic Product (GDP) for 2016. The six counties ranked high on the wildfire risk index contribute less than 2% of the State Gross Domestic Product. The ten counties – Asotin, Chelan, Ferry, Kitsap, Kittitas, Mason, Skamania, Spokane, Thurston and Yakima, ranked at medium-high for wildfire risk contribute cumulatively about 15 percent of the State GDP. The top three contributors to State GDP, King, Pierce and Snohomish Counties are ranked at medium-low from wildfire risks. Spokane County is the only county ranked higher than medium among the top five contributors to State GDP. Therefore, it is expected that major wildfire events are likely to have only a limited impact on the State GDP.

The indirect economic consequences including losses in work days because of poor air quality, loss of capital required for suppression efforts, interrupted access, losses in tourist income were not included within this analysis.

Wildfire Risk (WaSRI WF) and County GDP 2016

County	Landslide Risk Index (WaSRI L)	GDP 2016 (in Mil.)
Adams	Low	$746.07
Asotin	Medium-High	$618.43
Benton	Medium-Low	$10,627.85
Chelan	Medium-High	$4,363.01
Clallam	Low	$2,573.06

Wildfire Risk (WaSRI WF) and County GDP 2016		
County	Landslide Risk Index (WaSRI L)	GDP 2016 (in Mil.)
Clark	Medium	$18,682.64
Columbia	Medium	$144.20
Cowlitz	Medium	$4,474.88
Douglas	Medium-Low	$1,037.39
Ferry	Medium-High	$198.13
Franklin	Low	$3,356.16
Garfield	Medium	$97.44
Grant	Medium	$3,803.65
Grays Harbor	Medium-Low	$2,237.44
Island	High	$2,796.80
Jefferson	Low	$867.23
King	Medium-Low	$230,344.61
Kitsap	Medium-High	$12,082.18
Kittitas	Medium-High	$1,566.21
Klickitat	High	$1,004.05
Lewis	Medium	$2,573.06
Lincoln	Medium-Low	$347.25
Mason	Medium-High	$1,566.21
Okanogan	High	$1,678.08
Pacific	Low	$637.45
Pend Oreille	High	$354.63
Pierce	Medium-Low	$41,280.80
San Juan	High	$602.88
Skagit	Medium	$5,705.48
Skamania	Medium-High	$218.04
Snohomish	Medium-Low	$39,378.97
Spokane	Medium-High	$24,723.73
Stevens	High	$1,111.56
Thurston	Medium-High	$12,865.29
Wahkiakum	Low	$93.41
Walla Walla	Medium-Low	$2,908.67
Whatcom	Medium-Low	$10,068.49
Whitman	Low	$2,237.44
Yakima	Medium-High	$10,404.10

Risk to Environment

To assess the risk to environmental resources, the spatial land cover mapped data was overlaid with wildfire hazard layer. Forests, scrubland, wetland and cropland areas were identified as ecologically critical areas. The overlap between these areas of ecological importance and wildfire hazard areas (medium or higher exposure) was analyzed through spatial analysis in GIS software.

It is estimated that 22% of the state's ecologically critical resources are also at medium or higher wildfire exposure. The high degree of overlap among the ecologically critical resources is expected because of the nature of the hazard. Most wildfires originate in forested areas, which provide a fuel rich environment. The spatial analysis reveals that more than 50 percent of the ecologically sensitive areas in Island, Klickitat, Kittitas and Yakima Counties are also have medium or higher exposure to wildfires. In Asotin, Pend Oreille, Chelan, Ferry, Stevens, Okanogan, San Juan and Spokane Counties 30-45 percent of the ecologically critical areas are also at medium or higher wildfire exposure.

Lower intensity fires are a natural part of the forest ecosystem's adaptive cycle of succession. Following lower intensity wildfires, grasses germinate and grow to be replaced shrubs which in turn are preplaced by trees. Forests mature and as fuels build and wildland fires become increasingly probable. Low intensity fires reoccur repeating this adaptive cycle and fuels are again eliminated, increasing habitat diversity and continuing the natural forest succession regenerative processes.

Even naturally-occurring wildfires, however, can have a large, negative impact on an ecosystem. Fires burn over springs in scrub areas and can expose them to debris and to increased evaporation. Fires also lead to increased erosion, both from wind and water, which can make environmental recovery more difficult. Finally, wildfire can destroy important swaths of habitat for endangered animals such as sage grouse and pygmy rabbit. While fire is natural in the ecosystem, it isn't an unmitigated good for these species.

Fire's adaptive cycle has been defining Northwest forests since the last glacier receded about 13,000 years ago, however, human populations and a changing climate are altering this cycle. Our settlements are now encroaching on the Wildland Urban Interface (WUI), which has resulted in limiting the frequency of lower-intensity, fuel-removing fires. And these at-risk settlements have diverted wildland fire-suppression efforts away from protecting the forest to protecting structures. The greatest destruction resulting from high intensity fire are losses in ground cover. High intensity wildland fires render soils hydrophobic, increasing flood velocities, soil mobilization often causing permanent soil losses along with the ability of the forest to regenerate. This is most probable to high risk forest on slopes.

Also significant is that, with a warming climate, our resident pests are not being controlled naturally and new ones are arriving and filling vacant niches. Of particular concern are bark beetles that have historically had a limited impact. This reduced impact has changed with warmer weather, or in case of bark beetles fewer winter days below freezing along with the lack of low intensity fires, whereby beetle populations have exploded and decimated many eastern Cascade forests. These beetle-killed forests greatly increase the risk of high intensity wildland fires.

Environmentally Critical Areas at Risk from Wildfires	
County	Percent of County Ecologically Critical Area with Wildfire Exposure
Adams	0.00
Asotin	44.63
Benton	0.75
Chelan	39.03
Clallam	0.00
Clark	16.24
Columbia	19.04
Cowlitz	16.56
Douglas	3.06
Ferry	38.99
Franklin	0.00
Garfield	8.23
Grant	0.02
Grays Harbor	2.93
Island	82.08
Jefferson	0.04
King	12.71
Kitsap	23.93
Kittitas	61.30
Klickitat	65.69
Lewis	14.55
Lincoln	1.29
Mason	8.87
Okanogan	35.52
Pacific	0.00
Pend Oreille	42.86
Pierce	10.40
San Juan	35.29
Skagit	15.80
Skamania	11.71
Snohomish	20.05
Spokane	32.47
Stevens	37.43
Thurston	21.48
Wahkiakum	0.00
Walla Walla	7.20
Whatcom	11.90
Whitman	0.00
Yakima	55.33
Washington State	22.04

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