Earth

This chapter analyzes the growth distribution alternatives in relation to the region's geologic features, which include earthquakes, landslides/erosion, volcanic hazards, flooding, and coal mine subsidence. Each could cause a disaster; however, the severity of the impact and number of people and properties affected could depend on where and how growth is distributed under the different alternatives.

5.13.1 Affected Environment

A. PHYSICAL SETTING AND REGIONAL GEOLOGY

The formation of the Puget Sound region has been shaped by the movement and subduction of the earth’s crust and volcanic and glacial activity over millions of years. The region is a geologically active area. All or parts of the region are susceptible to the following hazards:

- Earthquakes
- Landslides/Erosion
- Volcanic Hazards
- Flooding
- Coal Mine Subsidence

The Puget Sound area landscape was largely carved and shaped by the glaciers that advanced and retreated during the period beginning about 26,000 years ago until nearly 10,000 years ago. Over time, the weight and movement of these glaciers carved the basins, valleys and hills between the Cascade Mountains to the east and the Olympic Mountains to the west. The deepest of these basins filled with water as the glaciers retreated, forming Puget Sound. In addition to shaping much of the topography of the region, the ice age glaciers deposited most of the soil that lies on or close to the surface. These soils affect many things, including where and how easily structures can be built, where farming and resource extraction is most appropriate and sustainable, and where natural geologic hazards are more likely to occur. Several principal classes of soils found in the region include:

- Lakebed sediments (sils and clays)
- Deposits from glacial runoff (sands and gravels)
- Glacial till (very dense mixture of all types of deposits)

Additionally, stream deposits (less than 10,000 years old) and artificial fill can be found in many locations.
The topography (sloped or flat) and type of soil present can create landslide, liquefaction\(^1\), and other geologic hazard areas in the region. Data from the King, Kitsap, Pierce, and Snohomish county Geographic Information Systems (GIS) have been collected to map the hazard areas in the region in Figure 5-13-1 (steep slopes/landslide, liquefaction, fault lines, floodways), including the main fault lines. Geologic hazard areas are often designated as Sensitive or Critical Areas and subject to additional restrictions or regulations by the local jurisdiction.\(^2\)

\(^1\) Liquefaction is the process by which loose, unconsolidated soils and fill respond to the shaking motion of an earthquake. This causes the soil to liquefy and flow like water, similar to quicksand, which strongly amplifies ground motion and is a major source of catastrophic damage.

\(^2\) List of County Critical Areas Ordinances: Pierce County Critical Areas Ordinance Title 18E, King County Critical Areas Ordinance 21A.24, Snohomish County Critical Areas Regulations Chapter 30.62B, Kitsap County Critical Areas Ordinance Title 19.
B. PRIMARY GEOLOGIC HAZARDS

Seismic Hazard Areas

The Puget Sound region has many faults, as shown in Figure 5-13-1. Faults are cracks in the earth’s crust and are the product of movement within the crust. The following are some of the major faults in the area:

- The Seattle Fault zone is a series of shallow crustal faults that stretches from Bremerton in Kitsap County east-west across King County to Issaquah.
- A shallow fault zone stretches from Gig Harbor to near the Tacoma Dome in Pierce County.
- The South Whidbey Island fault crosses the south end of the island and stretches southeast through the south Everett area in Snohomish County towards Duvall.
- The North Whidbey Island fault crosses the north end of the island, stretching southeast across northern Snohomish County.

These faults pass through or near several of the most populated cities in Washington: Bellevue, Everett, Seattle, and Tacoma. In addition to residential areas throughout the region, there are significant industrial land uses within these fault zones, specifically near the Boeing Plant in Everett, the Duwamish industrial area south of downtown Seattle, and near the Port of Tacoma. Major employment centers are also located in downtown Seattle, Tacoma, Renton, Bellevue, and Everett. An earthquake on one of the major faults could impact a large number of people and substantially disrupt businesses and industries in the region.

When a fault slips vertically or slides side-to-side, earthquakes can occur at shallow depths or miles below the surface. Huge earthquakes can occur in this region from the Cascadia Subduction Zone, which is located deep in the Pacific Ocean off the Washington coast. This is where the Juan de Fuca plate (a piece of the ocean’s crust) is sliding underneath the North American plate. A subduction zone earthquake has the potential to exceed a magnitude of 9.0. Historically, at least seven huge earthquakes might have occurred along the subduction zone over the last 3,500 years, the last being around 300 years ago (University of Washington, 2005a).

More than 1,000 earthquakes occur each year, mostly in the western half of Washington state. Many are small and not noticed by the public, but since the late 1800s, more than 20 damaging earthquakes have hit Washington (WADNR, 2005). A Federal Emergency Management Agency (FEMA) study in 2001 ranked Washington as the state with the second highest risk for economic loss caused by an earthquake (Seattle Fault Earthquake Scenario Project, 2005). A major earthquake could cause a loss of life and property throughout the Puget Sound region.

In February 2001, the magnitude 6.8 Nisqually earthquake hit the region. This was a shallow crustal earthquake, with the epicenter about 10 miles (18 kilometers) northeast of Olympia and about 52 meters deep (University of Washington, 2005b). The total federal disaster recovery costs were estimated to be $322 million dollars (FEMA, 2001).

Steep Slope/Landslide Hazard Areas

The Puget Sound region has many natural and human-made steep slopes covered with loose soil and rock. Loose materials on a steep slope create a landslide hazard area, where gravity tends to pull material down the slope. When the soil gets wet or saturated with water, the soil becomes increasingly unstable. Steep slopes can be very hazardous during an earthquake, when the motion can shake the loose material free. Wet soil on steep slopes can liquefy during an earthquake, with whole sections sliding away. Erosion from wind, water, lack of vegetation, or other reasons can also play a part in a slope becoming unstable and prone to sliding.
The steep slope and landslide hazard areas, which are present throughout King, Kitsap, and Pierce counties, are depicted on Figure 5-13-1. Note that steep slope data were not available for Snohomish County. The majority of the region’s mapped landslide hazard areas occur in the eastern portions of Snohomish, King and Pierce counties, predominantly in natural resource and rural areas, and along shorelines of Puget Sound, Lake Washington, and Lake Sammamish.

### Volcanic Hazard Areas

Just off the Washington coast, a piece of the earth’s oceanic crust (called the Juan de Fuca Plate) is sliding underneath the Washington coastline. In addition to the potential for earthquakes, as the plate slides deeper into the earth, some of the crust melts, and some of the melted crust, called magma, begins to rise. When magma builds up and rises, it seeks a vent or volcano in the earth’s surface. During an eruption, magma can be released, along with ash, steam, and other gases. The heat from the eruption can also melt glaciers and snow and cause large mudflows.

Volcanic hazard areas within the region are primarily linked to Mt. Rainier, and are largely located in Pierce County along the Carbon and Puyallup River valleys, although the risk of mudflows also extends into King County along river valleys that originate from Mt. Rainier. Historical data show that large mudflows, or lahars, have been triggered by volcanic activity (although not always preceded by an eruption) from Mt. Rainier, and have surged down the Puyallup River valley, reaching Commencement Bay. Rural areas in Pierce County, the city of Orting, and parts of the cities of Sumner and Puyallup could be covered by a large mudflow from Mt. Rainier. More extensive parts of the region could also experience ash fall from Mt. St. Helens if the winds were blowing towards Puget Sound during an eruption.

### Flooding

Most floods in the region occur when there have been extended periods of heavy rainfall or rapid snowmelt runoff from surrounding mountain ranges. Many areas, especially valleys, throughout the region are within the FEMA 100-year floodplain. Flooding occurs to some extent every year and is the most common natural hazard in King, Kitsap, Pierce, and Snohomish counties. The major rivers in King, Pierce, and Snohomish counties are greatly influenced by the amount of rain and snow received in the Cascade Mountains. Valleys, low-lying areas, and land near waterbodies like lakes and streams are more likely to experience flooding and property damage during major storms or wet seasons. Flooding can occur along the Puget Sound when rains, high tides and/or the right direction and intensity of winds combine. Flooding problems could also occur if a dam were to break upstream of a neighborhood in the region. In urban neighborhoods, localized flooding can occur if the stormwater system is over capacity or drains are blocked.

### Mine Hazards

Abandoned mines underlie several areas in King and Pierce counties and create the potential for significant damage if the ground above the mine gives way. There are no abandoned coal mines in Kitsap or Snohomish counties (WADNR, 2006).

### C. CURRENT TRENDS

Recent and ongoing studies into the extent and types of risks associated with geologic hazards have resulted in a greater understanding of what types of uses are appropriate for certain areas. The United States Geological Survey and the University of Washington are actively involved in research into the nature and location of geologic hazards. This research will continue to be invaluable in reducing and mitigating the risk associated with the region’s active geology because it is identifying localized conditions and likely effects of seismic activity in more detail, which allows the region to apply appropriate engineering measures in new development and in retrofitting existing facilities that might not be able to withstand potential seismic factors. Overall, the region is also increasingly recognizing the need for infrastructure that addresses risks posed by the region’s geography. High levels of investment are being directed to address earthquake-vulnerable highways and bridges throughout the region, including the Alaskan Way Viaduct and State Route 520.

### D. REGULATORY SETTING

Local land use regulations, such as Growth Management Act mandated critical areas regulations, typically restrict the type and location of development with regards to natural and geologic hazard areas. These development regulations vary between jurisdictions, but the Washington State Department of Community, Trade, and Economic Development has developed a model critical areas ordinance that covers recommended protections from erosion, landslide, seismic, mine, and volcanic hazards. The Federal Emergency Management Association has several programs that seek to limit
the number of structures within flood prone areas. In 2003, the Washington State Legislature adopted the International Building Code as the state standard building code. Provisions of this code mandate certain seismic safety standards for buildings located within the central Puget Sound region.

Each of the counties in this region have critical areas ordinances to implement the GMA:

- Pierce County Critical Areas Ordinance Title 18E
- King County Critical Areas Ordinance 21A.24
- Snohomish County Critical Areas Regulations Chapter 30.62B
- Kitsap County Critical Areas Ordinance Title 19

The purpose of these regulations is to protect critical areas from development and protect development from being impacted by a geologic hazard.

5.13.2 Analysis of Alternatives (Long-Term Impacts)

The timing, intensity, and location of events like earthquakes and other geologic hazards are very difficult to anticipate and greatly influence whether the impacts are minor or serious. Impacts from these natural hazards will also not occur uniformly across the region. Evolving research in the field of hazard mapping and risk assessment has resulted in information about the relative risks associated with different locations within the region. For this analysis, spatial data was assembled that identified known hazard areas within the region. The approximate amount of population and jobs that would be exposed to elevated risk within each alternative was then compared. Higher-risk areas for the following hazards have been mapped and analyzed: areas prone to liquefaction in an earthquake, areas subject to lahars from Mt. Rainier, FEMA 100-year floodways, and landslide prone areas.

A. IMPACTS COMMON TO ALL ALTERNATIVES

Local jurisdictions' critical area designations and regulations are a primary tool that would affect the number of people who would potentially be located in the areas where hazards are most likely to occur. Nonetheless, impacts from geologic hazards such as earthquakes, landslides, volcanic activity, and floods could include the following at any location in the region:

- Damage or collapse of buildings and transportation facilities
- Blocked access to buildings and roads
- Disrupted and damaged utilities
- Disrupted or disabled emergency and public services
- Altered physical landscape
- Economic loss
- Personal injury and loss of life

Areas within the region have the potential to experience these impacts regardless of the alternative selected. Development has already occurred in many areas that are particularly susceptible to these impacts. None of the alternatives anticipates decreases in existing development in these areas, although mitigation measures could help reduce the risks in these developed areas over time under all of the alternatives.

Urban Versus Rural Development

Areas such as metropolitan cities, core suburban and larger suburban cities typically have more comprehensive and some redundant utilities and roads to meet population demands. Similarly, there are typically several police stations, fire stations, and health clinics or hospitals in each of these heavily populated jurisdictions. If a natural disaster occurs, it is possible that alternate, functioning services and roads could be available or made usable in metropolitan cities, core suburban and larger suburban cities because more resources and options exist in those areas. In smaller suburban cities, unincorporated areas, and rural areas, there are potentially fewer duplicate services, which might make it more difficult to reach people affected by a natural disaster if major facilities, such as utilities and roads, are damaged.
With the exception of liquefaction/seismic hazard zones, growth in already densely populated areas might be less likely to be sited in presently undisturbed or undeveloped geologic hazard areas. Known liquefaction areas could significantly affect growth in some metropolitan and core suburban cities. Liquefaction areas in rural areas are largely in agricultural river valleys and along waterways, which might present limited development potential — and reduced risk to new development — due to existing critical areas regulations. Growth in smaller suburban cities and rural areas might have a greater potential to occur in or near landslide or volcanic hazard areas than growth in larger and metropolitan cities due to their greater proximity to Mt. Rainier and mapped landslide hazard and steep slope areas in the Cascade and Olympic mountain ranges.

**Landslide Hazards**

Landslide hazard areas exist in all four counties within the region. Growth in landslide hazard areas would only increase the risk of loss of life and property should a landslide occur and should be avoided. Certain activities such as vegetation and groundwater removal can make areas more prone to landslides. The majority of mapped landslide hazard areas in Snohomish, King and Kitsap counties are located in the eastern portions of those counties in designated natural resource areas, which have little potential for future development.

**Flooding**

Growth in flood zones (such as valleys, low-lying areas, and land near water bodies) is more likely to experience flooding than areas outside of flood zones. Creating new impervious surface area, such as roadways and parking lots, can add to flooding problems by reducing existing areas that presently naturally filter water, and by sending surface water to flow in new directions.

**Seismic Hazards**

Seismic hazards exist in all four counties within the region and there is no way of controlling seismic activity. Liquefaction areas and seismic faults depicted in Figure 5-13-1 occur throughout the region, in urban, rural, and natural resource areas. Existing structures should be retrofitted to be seismically sound and new structures should be built to comply with the standards set forth in the International Building Code.

**Coal Mine Subsidence**

Coal mines have the potential to cause settlement or collapse in their immediate vicinity, and can also affect groundwater levels and collect underground gases.

**B. ANALYSIS OF EACH ALTERNATIVE**

**GROWTH TARGETS EXTENDED ALTERNATIVE**

For Growth Targets Extended, 50 percent of the population growth distribution would be in metropolitan, core, or larger suburban cities and the other 50 percent would be split between smaller cities, unincorporated urban growth areas, and rural areas. For example, 80 percent is located in metropolitan, core and larger suburban cities.

With Growth Targets Extended, growth allocated to the more densely developed urban areas could be impacted by the presence of liquefaction prone and seismic hazard areas. Major faults pass through or near the cities of Bellevue, Everett, Seattle, and Tacoma, which would experience significant population and employment growth in this alternative. In addition, there are significant industrial land uses within these fault zones, specifically near the Boeing Plant in Everett, the Duwamish industrial area south of downtown Seattle, and near the Port of Tacoma, all of which would continue to serve as major employment centers in this alternative. Major employment centers are also located in downtown Seattle, Tacoma, Renton, Bellevue, and Everett, all of which are located near fault lines or liquefaction prone areas. An earthquake on one of the major faults could impact a large number of people and substantially disrupt businesses and industries in the region.

The 50 percent population growth and 20 percent employment growth in smaller suburban cities, unincorporated urban and rural areas might also be sited in locations within or adjacent to known hazard areas. Growth Targets Extended could increase population in areas, such as southeastern Pierce County, that could be impacted by volcanic activity, such as an eruption of Mt. Rainier.
METROPOLITAN CITIES ALTERNATIVE

The Metropolitan Cities Alternative would concentrate 70 percent of population growth and 85 percent of employment growth in metropolitan, core, and larger suburban cities, with 30 percent of population growth and 15 percent of employment growth in smaller cities, unincorporated urban growth areas, and rural areas. As geologic hazards are somewhat localized, impacts arising from an event in the region’s largest cities in the more densely populated portions of the region would affect a greater number of people than if more growth were more widely distributed in less populated areas. However, there are more redundant transportation, utility, and emergency services in larger cities, which could be a benefit if infrastructure were damaged by a geologic hazard.

Under the Metropolitan Cities Alternative, the 30 percent of population growth and 15 percent of employment growth in smaller cities, unincorporated urban growth areas and rural areas could increase the number of people who live areas like the Puyallup Valley. If a natural disaster such as a volcanic eruption or flood were to occur, the people might need to evacuate, which could be increasingly difficult in more populous smaller suburban cities that had limited evacuation routes. More dispersed development patterns in these areas, however, might mean that fewer people are impacted by localized hazard events.

The Metropolitan Cities Alternative would concentrate growth in areas that are already densely populated and largely covered with impervious surfaces. Existing stormwater management and treatment systems, along with upgrades to systems made as redevelopment occurs, have the potential to manage any increased stormwater associated with impervious surfaces. Growth in smaller cities, unincorporated and rural areas is more likely to create new impervious surface area as previously undeveloped areas are converted to more urban uses, which could require the development of new stormwater management systems to prevent flooding problems.

LARGER CITIES ALTERNATIVE

The Larger Cities Alternative would concentrate 80 percent of the population and employment growth distribution in metropolitan, core, and larger suburban cities, with 20 percent in smaller cities, unincorporated urban growth areas, and rural areas. The potential impacts for the Larger Cities Alternative could be very similar to the Metropolitan Cities Alternative. Slightly more growth would be concentrated in the large cities where more people could be affected if a natural hazard event impacted densely populated urban areas. Possible impacts in smaller cities, unincorporated urban growth areas, and rural areas would be similar to those described in the Metropolitan Cities Alternative.

SMALLER CITIES ALTERNATIVE

The Smaller Cities Alternative would concentrate 25 percent of the population and employment growth in metropolitan, core, and larger suburban cities, and 75 percent in smaller cities, unincorporated urban growth areas, and rural areas. In this alternative, fewer people would be concentrated in the region’s more densely populated urban areas, reducing risk from natural hazard events that have the potential to heavily impact liquefaction prone and seismic fault zones in the region’s larger cities. Wider distribution of population and employment around the region in smaller-scaled structures could minimize impacts in the event of a localized natural hazard event.

The wider distribution of growth in King, Kitsap, Pierce, and Snohomish counties has the potential to increase pressure to allow development in greater proximity to some identified hazard areas in designated natural resource areas. Responding to impacts caused by a geologic hazard could be more difficult in those unincorporated and rural areas that are more distant from emergency service facilities and multiple evacuation routes. Development in outlying suburbs, especially in Pierce County, has a greater potential to be close to landslide and volcanic hazard areas from Mt. Rainier.

The Smaller Cities Alternative would likely create some amount of new impervious surface area as a result of new developments in the outlying suburbs, requiring the installation of new stormwater management facilities to prevent localized flooding.
5.13.3 Cumulative Effects

Possible geologic impacts are both localized and regional in nature. Most geologic conditions would be relatively unaffected by factors outside the region. However, for flooding, cumulative effects of growth activities upstream would have a direct impact on downstream cities and towns in that, as cities and towns upstream build within floodplains, the fluvial characteristics become less predictable, and thereby put downstream populations at a greater risk of flooding.

5.13.4 Potential Mitigation Measures

Potential mitigation measures to limit the risk of adverse impacts from geologic hazards could include many approaches; a few are listed below.

- Existing regulations such as local jurisdictions’ critical areas ordinances and the International Building Code could be strengthened to require additional protections for structures locating within hazard areas. These protections could include increased setbacks from steep slopes or potential landslide areas, or restrictions on the type and intensity of development within floodways.

- Protections could also include strict building standards for new structures in the region, all of which are exposed to some risk from earthquake damage, and higher standards for structures locating within particular hazard areas, such as liquefaction zones or areas where the underlying geology could serve to amplify seismic waves.

- Further protection from earthquakes could be provided by programs that aim to retrofit existing buildings and infrastructure, instead of waiting for them to redevelop. These programs can be costly, but very effective at mitigating the risks associated with a major earthquake.

- Educational programs and disaster response planning can help mitigate the impacts of disasters by teaching and reminding people of what to do in the event of a disaster and could also improve government response to a disaster, limiting additional impacts that often occur after the actual disaster has happened. Examples of local jurisdiction plans include Pierce County’s volcanic hazards response plan (Pierce County, 1999) and Orting’s emergency evacuation plans if a volcanic event were to occur at Mt. Rainier.

- Additional research into the risks of geologic hazards.

5.13.5 Significant Unavoidable Adverse Impacts

None of the alternatives completely prohibits development on sites that are at risk for geologic hazards. Because single-family residences are allowed on most legal lots, often including those lots within designated critical areas or known hazard areas, development on these sites within known hazard areas will always pose some risk of adverse impacts from geologic hazards. This is true for all alternatives.

In addition, the central Puget Sound region is susceptible to earthquake and volcanic disasters that will severely impact many, if not all, residents in the region regardless of the alternative selected. These severe impacts could occur even if all potential mitigation measures are carried out.

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3 The word fluvial is used in geography and earth science to refer to all topics related to flowing water. Fluvial usually refers to rivers, streams and sometimes through flow, overland flow and percolation.