

# Chapter 12 Earth

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## 1 What are the characteristics of the region's physical setting and geology?

The physical form and geology of the central Puget Sound region has been shaped over millions of years by three major factors: the movement and subduction of the earth's crust, volcanic activity, and a series of glacial advances and retreats. These factors have resulted in a region bounded on the east and west by high, steep-sided mountains, lowland river valleys, and deep marine basins within Puget Sound. The Cascade and Olympic mountain ranges border the central Puget Sound region on the east and west, respectively. The alternating advance and retreat of glaciers carved out valleys, hills, and basins between these two ranges. The deepest basins filled with water as the glaciers retreated and sea levels rose, forming the inland sea of Puget Sound.

The region is geologically active. The movement of the earth's crust results in both seismic and volcanic activity. Off the Washington coast, in the Cascadia Subduction Zone, the Juan de Fuca plate is moving generally eastward and sliding under the North American plate. This movement creates earthquakes that can exceed a magnitude of 9.0. The sliding of the plates also creates volcanic activity as the plates melt the earth's crust and creates magma, which rises to the surface as lava flows or an eruption occurs of magma, ash, steam, and gases. Mt. Rainier, Mt. St. Helens, and Glacier Peak are all active volcanoes that have erupted during the past 300 years. Volcanic eruptions have produced large mud and debris flows (lahars) that flow down river valleys; large mudflow deposits occur in the Carbon, Puyallup, and Stillaguamish river valleys.

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### Which elements of WAC 197-11-444 are addressed in this chapter?

This chapter addresses:

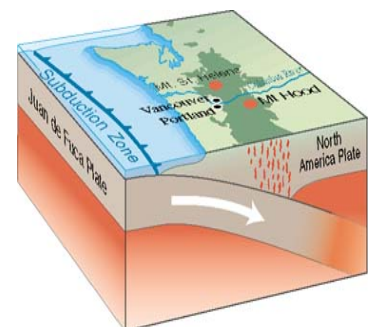
- Section (1)(a)(i) Geology
  - Section (1)(a)(ii) Soils
  - Section (1)(a)(iii) Topography
  - Section (1)(a)(iv) Unique physical features
  - Section (1)(a)(v) Erosion/enlargement of land area (accretion)
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### What is a subduction zone?

Subduction zones form where one continental plate slides underneath another. Sliding of the plates generates friction and heat, which can result in increased earthquake or volcanic activity in the area above the subduction zone.

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### Cascadia Subduction Zone



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The Cascadia Subduction Zone stretches from northern Vancouver Island to northern California.

Source: U.S. Geological Survey, 2009

Glaciers also deposited the materials that form the surface soils of the region. Coarse material such as sands and gravels were deposited in outwash or runoff as the glaciers retreated. Fine-grained silts and clays were deposited in lake basins or in deltas. Very dense, compacted till was left in areas where the weight of the glaciers created a very dense layer from a mix of sands, gravels, silts, clays, and boulders. Following the final retreat of glaciers about 10,000 years ago, streams and rivers carried these materials from hill slopes and deposited them in channels, floodplains, and deltas.

## 2 What are the region's primary geologic hazards?

Most of the region is susceptible to a number of geologic hazards (Exhibit 12-1), including earthquakes, landslides, liquefaction, flooding, and other hazards.

### Earthquakes

Major fault zones are areas where the earth's crust has moved and cracked. These zones present earthquake hazards. Several major faults occur in the central Puget Sound area and cross through or near major centers of population in Seattle, Bellevue, Everett, and Tacoma. The areas that these fault zones encompass are as follows:

- The Seattle fault zone has a series of shallow faults extending from Bremerton to Issaquah.
- A relatively shallow fault extends from Gig Harbor to near the Tacoma Dome.
- A south Whidbey Island fault crosses the south end of the island and extends southeast through south Everett towards Duvall.
- A north Whidbey Island fault crosses the north end of the island and extends east to Darrington.

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#### What is liquefaction?

Liquefaction occurs when loose, unconsolidated soils or areas of fill respond to the shaking motion of an earthquake. The soils liquefy or become like quicksand and can flow like water—this strongly amplifies the movement of the earth and is a source of catastrophic damage during earthquakes.

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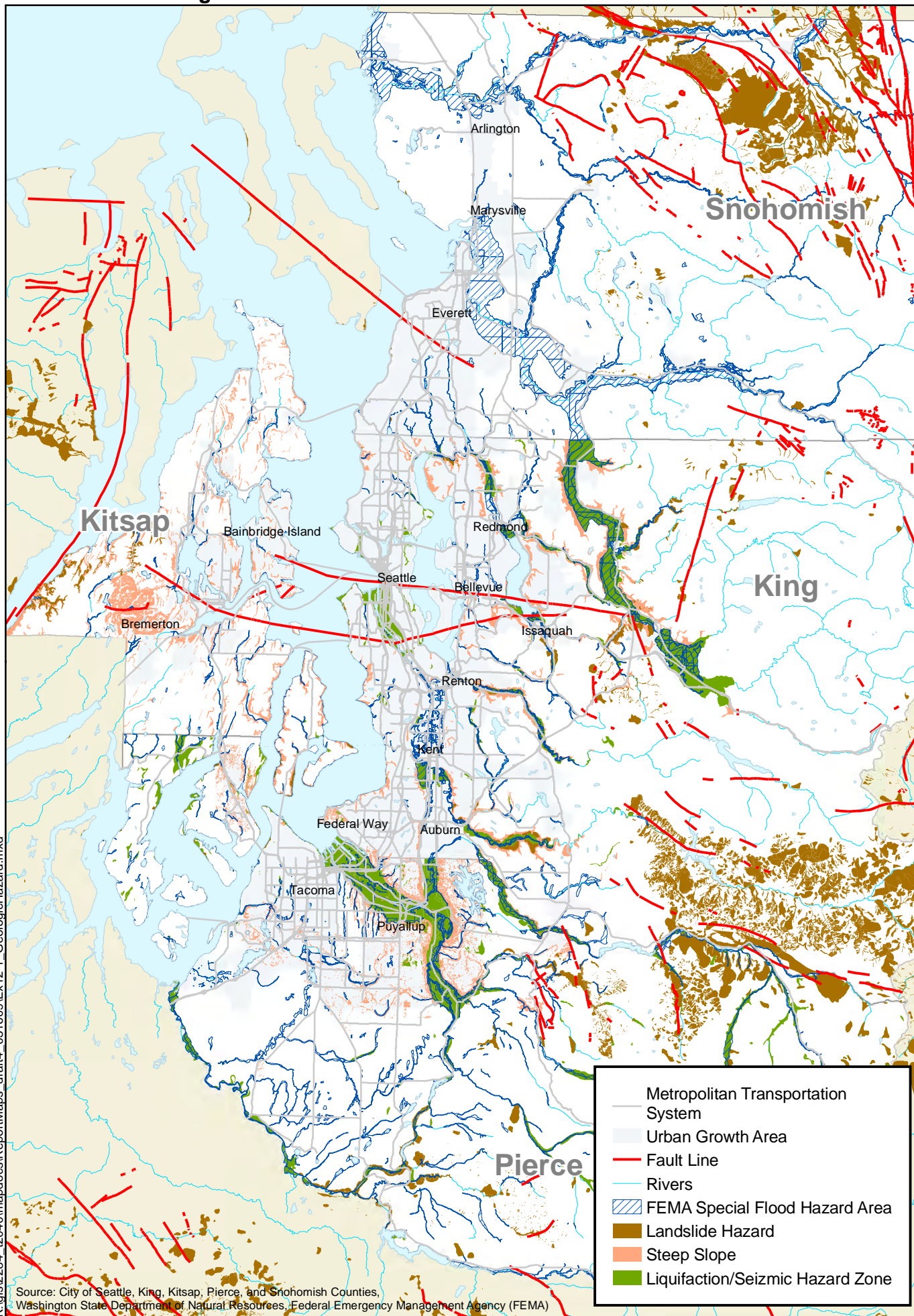
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#### Nisqually Earthquake Example

The Nisqually earthquake of February 2001 is the most recent large earthquake to occur in the region. The epicenter was about 10 miles northeast of Olympia and fairly shallow at 52 meters. With a magnitude of 6.8, the Nisqually Quake caused an estimated \$322 million worth of damage (FEMA, 2001).

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# Exhibit 12-1. Geologic Hazard Areas



- Metropolitan Transportation System
- Urban Growth Area
- Fault Line
- Rivers
- FEMA Special Flood Hazard Area
- Landslide Hazard
- Steep Slope
- Liquifaction/Seismic Hazard Zone

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Source: City of Seattle, King, Kitsap, Pierce, and Snohomish Counties, Washington State Department of Natural Resources, Federal Emergency Management Agency (FEMA)

These faults cross dense residential areas, as well as major industrial facilities, such as the Boeing plant in Everett, Harbor Island, the Duwamish industrial area south of downtown Seattle, and the Port of Tacoma. Major elements of the transportation infrastructure, including the floating portion of the Evergreen Point Bridge and the Alaskan Way Viaduct, are known to be particularly vulnerable to seismic activity. The Alaskan Way Viaduct was damaged by the Nisqually earthquake (magnitude 6.8) in 2001 and could experience catastrophic failure in a future earthquake. Many other elements of the transportation and utility infrastructure (dams, water supply, sewer, and energy) are vulnerable to damage during earthquakes; however, the extent of damage will depend on the location of the epicenter and the magnitude of the earthquake.

The region experiences thousands of small earthquakes every year that do not result in significant damage. The Washington Department of Natural Resources estimates that more than 20 damaging earthquakes have occurred in the region since the late 1800s. The very large Cascadia Subduction Zone earthquakes of magnitude 9.0 or larger are estimated to have occurred at least seven times in the last 3,500 years, with the last one occurring about 300 years ago.

When earthquakes occur, the damage to infrastructure results from large earth movements, settlement of the surface, soil liquefaction, landslides, and/or tsunamis. Significant damage is most likely to occur where nonstructural fill has been placed, or where soft, unconsolidated soils have been deposited in valleys, old lake beds, or shorelines. Areas susceptible to liquefaction include areas of fill in Seattle along the Puget Sound shoreline, along the Cedar River in Renton, the area between Woodinville and Redmond, around the edges of Lake Sammamish, the area between Kent and Auburn, and the area between Mt. Rainier and Commencement Bay. Low-lying shoreline areas could be subject to damage from tsunamis.

### **Flooding**

Severe flooding occurs in the region during extended periods of heavy rainfall or during rain-on-snow events, when rapid

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#### **What is a tsunami?**

A tsunami is a series of waves created when a large volume of a body of water, such as an ocean, is rapidly displaced. The Japanese term is literally translated into “(great) harbor wave.”

Earthquakes, volcanic eruptions, and other underwater explosions (detonation of nuclear devices at sea), landslides, asteroid impacts, and other mass movements above or below water all have the potential to generate a tsunami. Because of the immense volumes of water and energy involved, the effects of tsunamis can be devastating.

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melting of snow from mountain slopes combines with runoff from rainfall, creating large amounts of water that rapidly enters streams and rivers (Exhibit 12-1). Because of the large number of rivers and streams, much of the area is in Federal Emergency Management Agency (FEMA)-defined 100-year floodplains. Some flooding occurs every year and floods are the most common natural hazard in the region. Transportation facilities can be impassable or damaged during flooding. Facilities in low-lying areas in valley bottoms, and also near wetlands, rivers, and streams are the most likely to experience flooding and are most susceptible to flood damage. Shoreline areas of Puget Sound are subject to flooding when storms with heavy rain coincide with high tides and winds that push water towards the land. Significant localized flooding has occurred in Seattle and other urban areas when storm drains were blocked or the intensity of rainfall overwhelmed the stormwater drainage system.

The increase in impervious surface, as forests were removed and urban areas developed, has resulted in increased rates of runoff and high peak flows in streams and rivers. Impervious surfaces in a watershed can increase flooding problems downstream. Development and impervious surfaces within floodplains, in particular, remove natural flood storage capacity and increase the frequency of flooding and the damage caused by flooding.

Much development has occurred within floodplains and estuaries in the region. Areas in the central Puget Sound region that have experienced significant loss of floodplain and estuary habitat include the Green/Duwamish, Puyallup, and Snohomish river systems (Exhibit 12-2). The loss of floodplain water storage functions results in a greater risk of flooding when levees fail. In addition, high costs are associated with maintaining levees or repairing damage to critical infrastructure, including bridges, roadways, and rail facilities. During the past several years, in 2006 and 2008, devastating floods occurred in many central Puget Sound region rivers, where development in floodplains resulted in significant damage to property and transportation infrastructure.



Areas in flood zones and along large water bodies and shorelines are more susceptible to flooding.

Source: FEMA, 2008

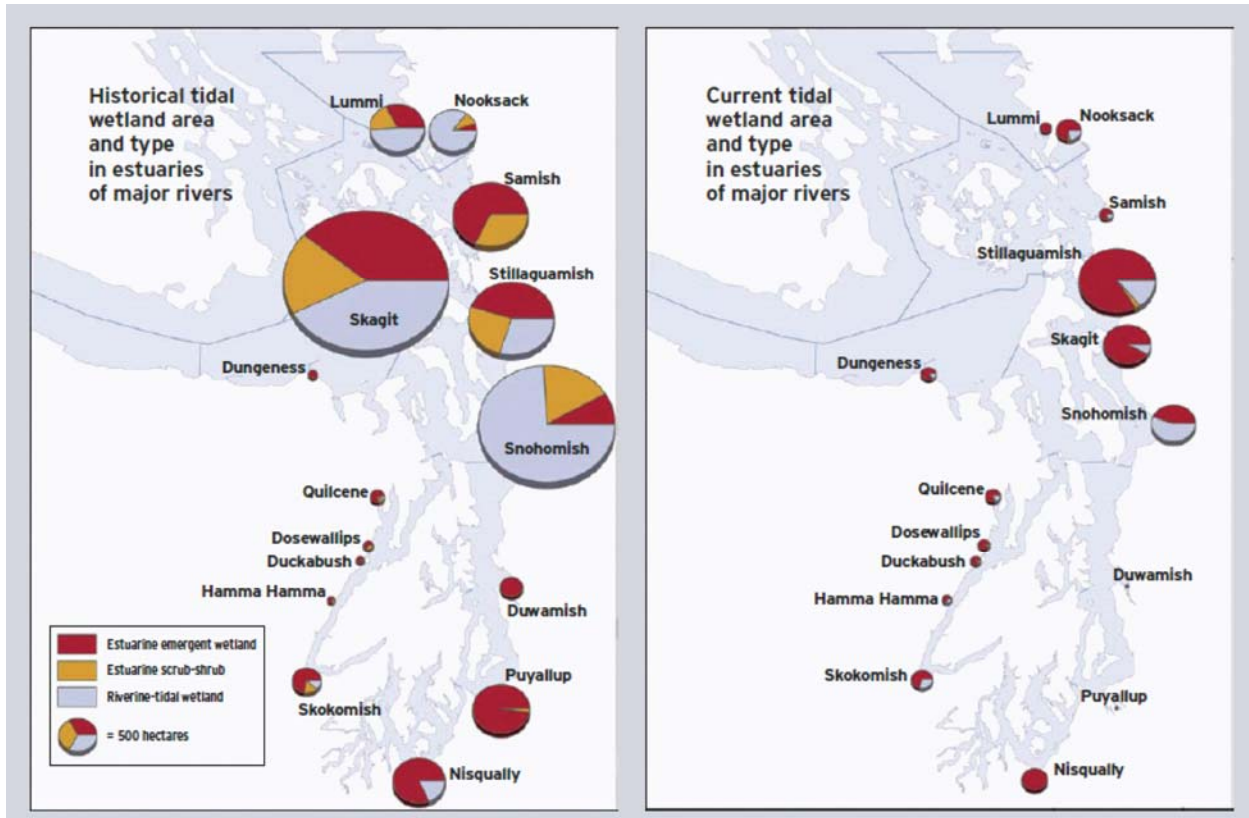
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**Areas with significant loss of floodplain and estuary habitat:**

- Green/Duwamish
  - Puyallup
  - Snohomish
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Exhibit 12-2

### Historical and Current Tidal Wetland Area and Type in Estuaries of Major Rivers



### Landslides and Erosion

The central Puget Sound region has many areas of naturally occurring steep slopes. Steep slopes have also been artificially created in the course of constructing residential, commercial, and industrial developments (e.g., steep road embankments). The Puget Sound shoreline is characterized by steep coastal bluffs formed in loosely consolidated or unconsolidated materials that easily erode and slump as gravity pulls material down the slopes.

Landslide hazards can be created when vegetation is removed from steep slopes, when soils become saturated, and particularly where areas of very permeable soils are located over layers of impermeable till or compact till. Water infiltrates through the permeable layers until it becomes restricted at the impermeable layers. The soils above the impermeable layer become saturated and tend to slide downhill across the



Steep slopes are a high risk area for landslides.

Source: Wikipedia, 2008

impermeable layer. This combination of soils causes many of the landslides along Puget Sound roadways and shorelines. Wind and water erosion, particularly during winter storms, can also lead to slope instability and landslides. Steep slopes, especially when soils are wet, can become unstable or liquefy during earthquakes, resulting in large sections sliding away.

Steep slopes and landslide hazard areas are regulated as critical areas in most local land use ordinances; therefore, building on steep slopes is currently restricted. However, many steep slopes and shorelines have already been built on in the region, resulting in significant areas of infrastructure that are subject to landslide hazards.

### **Sea Level Rise, Coastal Erosion, and Coastal Flooding**

A particular natural hazard that may become more prevalent in the next several decades as a result of climate change is sea level rise, as well as a resulting increase in coastal erosion and bluff landslides. Predictions about the extent of sea level rise in Puget Sound that is expected to occur due to global warming by the year 2050 range from a low estimate of 3 inches to a high estimate of 22 inches (University of Washington Climate Impacts Group, 2008). This sea level increase could expose new areas to wind and wave erosion and landslides, potentially damaging existing roadways and buildings that are adjacent to the shoreline.

Sea level rise could also worsen coastal flooding during storm events in low-lying areas of the Sound that do not currently experience such flooding.

### **Volcanism**

Volcanic hazards in the region are mostly linked to Mt. Rainier and, to a lesser extent, Glacier Peak. The Carbon and Puyallup river valleys have historically experienced large mud flows that extended from Mt. Rainier all the way to Commencement Bay. Some tributary streams in King County have also experienced historic lahars. Many of the rural areas of the Puyallup River valley, including the cities of Orting, Sumner, and Puyallup, could be covered by a large mud flow from Mt. Rainier. The




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Mount St. Helens erupted on May 18, 1980.  
Source: U.S. Geological Survey, 1980

communities of Darrington and Arlington could be affected by lahars from Glacier Peak.

### **Coal Mine Subsidence Hazards**

Small, localized areas in King and Pierce counties are underlain by abandoned coal mines. These areas could be subject to damage if the ground above the mines were to give way.

### **3 What regulations affect geologic hazards?**

The Growth Management Act mandates critical area regulations that typically restrict the type and location of development in certain areas. Critical areas can include steep slopes, seismic hazard areas, 100-year floodplains, and volcanic hazard areas. These regulations are developed and administered at the local level, and the types of restrictions and level of enforcement vary across jurisdictions. The guidelines developed by the Washington Department of Community Trade and Economic Development recommend providing protection from erosion, landslide, seismic, mine, and volcanic hazards. In addition, the state building code mandates seismic safety standards for buildings.

Restrictions on development in flood hazard areas are mostly governed by FEMA and the availability of flood insurance through the National Flood Insurance Program (refer to Flooding section under Question 2). Despite current restrictions, much development has occurred prior to regulation and development continues to occur despite restrictions.

### **4 What impacts are common to all alternatives?**

Specific geologic hazard impacts would be determined during the project-level environmental review for the projects included in the Transportation 2040 alternatives. Effects that are potentially common to all alternatives are discussed below.

#### **Long-term Effects**

The entire Metropolitan Planning Area in Transportation 2040 may be subjected to earthquake shaking and is considered to have a moderate to high seismic risk. North-south

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#### **What is the difference between plan-level and project-level environmental review?**

This FEIS is a plan-level (rather than a project-level) EIS. Accordingly, alternatives are defined and environmental effects are evaluated at a relatively broad level. More detailed project-specific environmental review will be developed as appropriate in the future for projects identified in the Transportation 2040 plan that are selected for implementation by their respective sponsors, for example, Washington State Department of Transportation (WSDOT), transit agencies, and local jurisdictions.

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transportation corridors would cross the Seattle Fault. Each corridor in the plan area includes soils prone to liquefaction, particularly fill soils, tidal flats, and other unconsolidated deposits. Earthquake-induced soil liquefaction could result in a loss of soil strength, settlement, lateral spreading, and landslides. The magnitude of soil movement and loss of strength is a function of many factors, including soil thickness, soil quality, groundwater level, and the magnitude and location of the seismic event.

Existing steep slopes are conducive to landslides. Landslides can be triggered by a seismic event, by excessive rainfall that could destabilize slopes, or project construction that traverses or cuts into a steep slope.

Facilities associated with the ferry system, as well as road and transit facilities located near the coast, could be subject to potential tsunami hazards following earthquakes. These facilities would also be potentially affected by sea level rise due to global climate change. Designs of new and/or expanded facilities would probably take predicted sea level rise into account and be less likely to be affected than existing facilities.

The design of new or expanded transportation facilities would comply with all applicable building codes and current or updated seismic code requirements. New facilities would be more likely to survive earthquake impacts than older existing transportation infrastructure that was built to less stringent seismic standards.

Much of the region's infrastructure already occurs in areas subject to geologic hazards. Because all alternatives build on the existing system, they would be subject to impacts from geologic hazards that could potentially occur at any location in the region, including:

- Collapse or damage to buildings or transportation facilities
- Blocked access to buildings or roads
- Damaged or disrupted utilities



Older transportation infrastructure is particularly susceptible to seismic hazards.

Source: U.S. Geological Survey, 2004

- Disrupted or disabled emergency services
- Personal injury and loss of life
- Economic loss and disruption of business activities
- Disruption of food supplies

The development of transportation facilities has already occurred in areas in the region that are subject to these hazards. None of the alternatives will decrease transportation development in already developed areas. However, the development of individual projects, the use of mitigation measures to reduce risk, and the incorporation of newer and improved design measures could reduce the vulnerability of the region to these hazards over time for all the alternatives.

Because all alternatives include replacement of the Alaskan Way Viaduct and improvement of other facilities to meet current seismic safety standards, all the alternatives would reduce the risk of earthquake hazards.

### **Construction Impacts**

Potential impacts that could occur during construction include landslides, vibration, dewatering and erosion, and water quality impacts from construction over or near water. Construction could cause erosion impacts associated with vegetation removal, fill placement, cutting into the toe of slopes, and removal or stockpiling of spoils. Earthwork could cause silt-laden runoff to be transported off-site, potentially degrading water quality in local surface waters. The severity of potential erosion would be a function of the quantity of vegetation removed, site topography, and the volume of soils stockpiled. Soils disturbed during construction would be revegetated and would not experience long-term erosion impacts.

## **5 What effects are specific to each alternative?**

The types of effects described in the response to Question 3 could occur under any of the proposed Transportation 2040 alternatives, including the Baseline Alternative. This question does not seek to identify specific seismic hazards. Instead, it uses the amount of new transportation infrastructure contained

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### **Why does this FEIS not list the specific environmental effects caused by each alternative?**

Each of the Transportation 2040 alternatives contains hundreds of individual projects. If constructed in the future, these projects could affect the region's built and natural environments.

For some environmental disciplines, such as transportation or air quality, these projects could affect the environment in the vicinity of the project and also could collectively affect the regional environment. For these disciplines, this FEIS contains an analysis to evaluate the potential regional effects of these projects. The localized effects for these environmental disciplines will be identified in a future project-level environmental review.

For other environmental disciplines, such as earth, individual projects could be affected by the seismic hazards in their vicinity, but would not be affected by seismic hazards elsewhere in the region. Therefore, this FEIS does not contain a regionwide analysis for these disciplines. Future project-level environmental review will identify the specific localized effects on these environmental areas.

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in each alternative to compare the possible total exposure to seismic hazards in the region.

As noted in the sidebar, this plan-level FEIS will not list the specific individual effects that could result from all of the projects contained in each Transportation 2040 alternative. In addition, it is not practicable to conduct a regionwide evaluation of seismic hazards from all projects. Therefore, this plan-level FEIS does not contain a regionwide analysis of seismic hazards.

However, it is possible to provide an approximation of which alternatives could result in the greatest number of seismic hazards. The Transportation 2040 alternatives contain varying levels of new transportation infrastructure (Exhibit 12-3), and it is likely that the alternatives with the most new infrastructure would result in the greatest number of seismic hazards.

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**What is a lane mile?**

The term lane mile is used to describe the size of a transportation project because it accounts for the width of a project in addition to its length.

For example, one mile of a two-lane highway equals two lane miles. Therefore, a project that widens four miles of a two-lane highway to four lanes is said to have created eight new lane miles.

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**Exhibit 12-3<sup>1</sup>**  
**Miles of New Infrastructure Included in Each Alternative**

Facility Type	Base Year 2006	Baseline Alt	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Preferred Alt
Systemwide freeway and arterial lane miles	12,806	13,153	13,352	14,013	13,540	13,489	13,329	13,764
New freeway and arterial lane miles	-	348	546	1,208	735	683	523	958
Portion of new lane miles in new corridors	-	30	40	240	218	159	40	248
Light rail miles	2	55	55	82	55	82	82	86
New light rail miles		53	53	80	53	80	80	84
Commuter rail miles	74	82	82	82	82	82	128	128
New commuter rail miles	-	8	8	8	8	8	54	54
Total new miles of road and rail	-	409	607	1296	796	771	657	1096
Percent increase from 2006	-	3%	4%	9%	6%	5%	4%	7%
Nonmotorized facility miles	570	600	747	745	740	745	1058	1123
New nonmotorized facility miles	-	30	177	175	170	175	488	553

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<sup>1</sup> This exhibit has changed since the DEIS.

As shown in Exhibit 12-3, all of the alternatives contain similar amounts of new infrastructure, which is measured as a percentage of the total system (3 to 9 percent). Alternative 2 contains the greatest number of new miles of road and rail, and the Preferred Alternative contains the second-greatest number of new miles. The Baseline Alternative contains the fewest number of new miles. Of the action alternatives, Alternative 1 contains the fewest new miles of roads and rail. Therefore, Alternative 2 would likely result in the highest number of seismic hazards, with the Preferred Alternative slightly lower, and the Baseline Alternative would likely result in the lowest number. Among the action alternatives, Alternative 1 would likely result in the lowest number of seismic hazards. The number of effects resulting from Alternatives 3, 4, 5, and the Preferred Alternative would likely fall between the overall number of effects expected for Alternatives 1 and 2.

All alternatives also increase total vehicle trips compared to the 2006 base year, although Alternative 2 is the only action alternative with a higher number of vehicle trips than the Baseline Alternative. The higher number of trips would increase the impact from an earthquake or other geologic hazard because more vehicles would be exposed to the hazard.

The comparisons presented here are intended to approximate the number of effects expected from each alternative and do not identify specific seismic hazards. Future project-level environmental review will identify these effects.

The Baseline Alternative does not include replacing the floating portion of the Evergreen Point Bridge, so the seismic hazards associated with the current bridge would be greater under this alternative than under the others.

Alternatives 2 and 3 include investments in the ferry system to accommodate increased demand on some routes. The design of new or expanded facilities would comply with all applicable building codes and current or updated seismic code requirements; thus, these new facilities would be more likely to survive earthquakes than older facilities. With a greater number

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**Chapter 4: Transportation**

For more information about vehicle trips and other modeling results, please refer to Chapter 4: Transportation.

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of people using the ferry system, this increase could potentially expose more people to hazards in the event of earthquake-associated tsunamis.

Some impacts from particular alternatives would depend on where new projects are located. Alternatives that expand roadways or arterials adjacent to the shoreline could increase the risk from coastal flooding, sea level rise, and coastal erosion, as well as tsunamis. Liquefaction hazards are more likely in areas near lakes, wetlands, agricultural areas in river floodplains and estuaries, or areas of fill, so expansion of facilities in these areas could increase the risk of hazards from earthquakes and potential flooding.

The Preferred Alternative includes the second-greatest number of new miles of roads and rail. Therefore, the Preferred Alternative would likely result in the second-greatest number of potential seismic hazards.

## **6 What are the likely cumulative effects?**

Cumulative effects of growth and development would likely increase the incidence and severity of flooding downstream of areas with increased development.

Cumulative effects of growth and development along Puget Sound shorelines could increase the risk from sea level rise, coastal erosion, and coastal landslides, as well as tsunamis.

Cumulative effects of growth and development could increase the pressure to build near landslide hazard areas, increasing the risk of impacts from landslides.

## **7 How can these effects be mitigated?**

Incorporation of improved risk assessments in the planning and design of individual transportation projects can help minimize impacts from natural hazards. Such assessments can be used to determine the location and design of projects to minimize the risk of damage.

Potential mitigation measures could include the following:

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### **What are cumulative effects?**

Cumulative effects address the impact on the environment that results from the incremental impact of the action being considered when added to other past, present, and reasonably foreseeable future actions, regardless of what agency or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time.

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- Improve local land use codes to strictly prevent building and development in natural hazard areas, decreasing the risk of damage from these hazards.
- Increase the setbacks from steep slopes, restrict new development in floodplains, prohibit development in volcanic hazard areas, and restrict development on shorelines, beaches, and coastal bluffs.
- Improve current flood insurance programs to prevent development in high flood hazard areas and prevent rebuilding in flood hazard areas following flood damage.
- Increase the safety standards in building codes to reduce risk of damage from earthquakes or flooding. Safety standards that are based on the risk of particular locations (e.g., risk of liquefaction or flooding) could further reduce the potential for damage.
- Restoring some existing hazard areas that are currently increasing the risk of damage could reduce the overall risk of impacts from these hazards. Examples are levee setback projects, removal of existing structures from floodplains, purchase and protection of steep slopes, and removal of structures on shorelines and coastal bluffs.
- Retrofit existing buildings to improve seismic safety.
- Conduct emergency preparedness training for all communities in the region.

## **8 Are there significant unavoidable adverse impacts?**

None of the alternatives prohibit the development of transportation facilities in areas with natural hazards. All of the alternatives maintain and/or expand transportation infrastructure in hazard areas. Therefore, some unavoidable adverse impact risk from natural hazards exists for all the alternatives. Facility design for future project-specific actions would meet current design standards and consider geologic and seismic hazards that potentially affect the project.

The Baseline Alternative, which does not include replacement of the floating portion of the Evergreen Point Bridge, could result in unavoidable adverse impacts to the bridge due to potential catastrophic damage from a large earthquake.