Chapter 4.4
Landslide Hazard Risk Assessment

Introduction

Washington State is prone to landslides. On March 22, 2014, the deadliest landslide in U.S. history occurred two miles east of Oso in Snohomish County along State Route 530. Higher than normal rainfall and other factors contributed to the collapse of a portion of an unstable slope, north of the Stillaguamish River, generating an unprecedented debris-avalanche flow that crossed the river and covered nearly one-half square mile. The landslide killed 43 people and buried over 40 homes and other structures in a rural neighborhood known as Steelhead Haven.

The United States Geological Survey (USGS) estimated that the area overrun by the landslide moved 18 million tons of sand, till, and clay – enough material to cover approximately 600 football fields 10 feet deep. The landslide was believed to have reached an average speed of 40 miles per hour. Countless citizens and local, state, and federal personnel including staff from Thurston County Emergency Management assisted Snohomish County during the recovery.

Definition

A landslide is the movement of rock, soil, or other debris down a slope. In general, the term landslide covers a wide range of ground movement, such as rock falls, deep failure of slopes, and shallow debris flows. Mudflows (or debris flows) are flows of rock, earth, and other debris saturated with water. They develop when water rapidly saturates the ground from precipitation or a sudden influx of water that destabilizes the ground. As materials give way to gravity and move down a slope, a flowing river of mud or "slurry" can reach avalanche speeds and grows as it picks up trees, rocks, and other materials along the way.

Area of Impact

For the purposes of the hazard risk assessment, the landslide hazard area in Thurston County is defined as a combination of the following areas (see map 4.4.1):

1. Areas with slopes that are 40 percent or greater (slope was calculated using light detection and ranging or LIDAR using GIS); and
2. Washington State Department of Natural Resources mapped known and historic landslides database.

General building stock and critical facilities and known property replacement cost values were overlaid with the landslide hazard area. Using GIS, population exposure, building exposure, and dollar-value estimates of damage were generated to characterize a hazard risk rating (see Impacts and Vulnerabilities).

The Washington State Department of Natural Resources Geological Survey has mapped shallow and deep-seated landslide occurrences and landslide landforms along the entire Thurston County marine shoreline zone and the shorelines of Capitol Lake. Though useful, the data is not a comprehensive summary of all landslide events and hazards for Thurston County. Geologists mapped data based on interpretation of aerial photos, LiDAR data, topography, and field visits. This information is useful as a reconnaissance-level screening tool, but it is no substitute for a site-specific evaluation of geological conditions.

GIS exposure analysis shows that most of Thurston County's marine shoreline is vulnerable to landslides (Map 4.4.1), especially near bluffs.1, [2] Residences near steep slopes are potentially at risk for landslide hazards in the following areas: Totten Inlet, Carlyon Beach, Hunter Point, Eld Inlet, Budd Inlet, Henderson Inlet, Nisqually Reach, Summit Lake, Capitol Lake, Lake St. Claire, and Clear Lake.

Extent

Extreme winter precipitation such as heavy rain or rain following heavy snow produces most landslides. Landslides are also triggered by earthquakes and volcanoes. However, a landform's stability can be compromised by construction of buildings, roads and other infrastructure, and other activities such as logging and mining.

Severity can be measured in total cost of damages, impacts to transportation or utility systems, displaced households, or in terms of injuries and fatalities. The landslides on Steamboat Island Peninsula in winter 1998-1999 – the most damaging landslide recorded in Thurston County's history – cost $24 million in damages and response and recovery costs. This slow-moving landslide caused no serious injuries or deaths, but many residents in the densely developed Carlyon Beach community lost their homes. This incident did not impact the region's residents outside the affected area, but Thurston County staff, other emergency management personnel, and local area residents were significantly impacted by their losses.

The severity of a landslide can also be measured in terms of its size and composition: from a thin mass of soil a few yards wide to deep-seated bedrock slides miles across. The travel rate of a landslide can range from a few inches per month to many feet per second depending on the slope, type of material, and amount of saturation with water.

Factors that Contribute to Landslides

Landslides are caused by a variety of factors including:

- Earthquake induced stressors
- Erosion caused by rivers, glaciers, or ocean waves
- Human activity can drastically modify landforms and groundwater conditions – development activities with poor drainage control, cutting, filling, and grading along roads, logging practices that remove timber from steep slopes, and leaking pipes
- Hydrologic factors – Abundant rain, high water tables, little or no ground cover
- Increase of lateral pressures – Hydraulic pressures, tree roots, crystallization, swelling of clay soil
- Load - Weight of rain/snow, fills, vegetation, stockpiling of rock or ore from waste piles or from human-made structures
- Regional tilting – geological movements
- Volcanic eruptions

Landslide prediction is difficult. Most Puget Sound shoreline landslides occur from October through April, peaking December through February. The USGS has researched past shoreline landslides and rainfall levels in the Seattle area to identify when such landslides are likely to occur. One measure is a formula called the "precipitation threshold." The cumulative precipitation threshold measures precipitation over the previous 18 days and indicates when the ground is saturated enough to be susceptible to landslides. Between 3.5 and 5.3 inches exceeds this threshold.

The Washington State Department of Ecology Shorelands and Environmental Assistance Program summarizes where slides are likely to occur along marine shorelines[3] in Figure 4.4.1.

Figure 4.4.1 Areas Where Landslides Occur

Where Landslides Occur	Factors
Sites of previous landslides	Large, deep-seated slides tend to be a reactivation of existing landslide complexes. Slope stability maps can provide an excellent indication of unstable areas. A competent geological analysis can usually provide an estimate of stability of problem areas on a site. It cannot reliably provide a probability of failure or an exact map of the area to be affected.
Steep slopes	Steep slopes are typically found along shorelines where centuries of wave or river currents have eroded the toe of the slope. Most steep slopes around Puget Sound have experienced sliding in the past one or two hundred years.
Benches	Relatively level benches on an otherwise steep slope often indicate areas of past slope movement.
Sites where drainage is causing a problem	Landslides are often triggered by the failure of drainage systems. Large amounts of water flowing from driveways, roof areas, roads and other impermeable surfaces can cause slides.
Sites where certain geologic conditions exist	Landslides occur where certain combinations of soils are present. When layers of sand and gravel lie above less permeable silt and clay layers, groundwater can accumulate and zones of weakness can develop. In Puget Sound, this combination is common and widespread. Glacial outwash, often Esperance Sand or gravel overlies the fine-grained Lawton Clay or Whidbey formation.

Despite the difficulty in predicting landslides, the environment provides visual indicators of where the earth is moving. Discovering sites of prehistoric landslides is difficult, as telltale signs are often obscured by vegetation or human development. The Washington State Department of Ecology describes warning signs of earth movement[4] in Figure 4.4.2.

Figure 4.4.2 Warning Signs of Landslides

Environment	Warning Signs
Landscape	Head scarps or steep cliffs at the top of a slope Benches, scarps, and large cracks Exposed clays uplifted on the beach Hummocky and uneven terrain Trees or large blocks of clay partially buried in beach, not just drift logs
Roads, Utilities, Buildings	Sagging or taut utility lines Separation of foundation from sill plate Growing cracks in walls and window corners Broken or leaking water or sewer lines Doors not closing properly Significant cracking of concrete slabs and pavement
Vegetation	Tilted trees Curved trees Split trunks and stretched roots Large clusters of trees of similar age (often Alder)
Water	Small ponds on otherwise sloping terrain Disrupted natural drainage Unusually heavy or muddy seepage Unusual increase or decrease in flow from springs

Effects of Climate Change

Research and climate forecasts provide clear evidence that long-term climate change will have a measurable impact on the frequency of landslides. The University of Washington Climate Impacts Group published a detailed report on the state of science on climate change and its effects within the region titled, "State of Knowledge: Climate Change in the Puget Sound." The report identifies several factors that will influence landslides for communities around the Puget Sound.

Air temperatures are increasing in the Puget Sound Region. They are projected to warm rapidly during the 21st century. By mid-century, warming will be outside of the range of historical variations. Warming is projected for all seasons but will be greatest for summer. As the risk for wildfires increases with warmer drier summers, the risk for landslides could increase for steep slopes that lose their vegetation from wildfires. As a result of warmer

winters, watersheds will become increasingly rain dominant and streamflow is projected to peak earlier in winter and decrease in spring and summer. Winter streamflow is projected to increase by 28 to 34 percent on average by the 2080s. For the Thurston County planning area, excess saturation of soils during warmer and wetter winters will make steep and unstable slopes vulnerable to landslides and mudslides.

Overall annual precipitation levels are forecast to remain the same, but there will be greater seasonal variation. Summers will become drier, and winters will be wetter. The frequency of the region's peak 24-hour rain events is expected to more than triple by the end of the 21st century. Such heavy storms are also expected to become more intense, with greater rainfall occurring in shorter periods of time. The region's frequency and risks for landslides is likely to increase due to the effects of more intense winter storms.

Previous Incidents

Several landslides have impacted Washington State and the Thurston County region over the last several decades. Previous incidents offer insights into the types of losses that Thurston County communities could experience in future landslide activity.

December 1-7, 2007, Severe Winter Storms, Flooding, Landslides, and Mudslides. DR-1734.

On December 3, an estimated 97 households were isolated by a complete washout of Cedar Flats Road in northwestern Thurston County. Washington State Department of Natural Resources' landslide reconnaissance found that heavy "...warm rains rapidly melted snow on the ground in Capitol State Forest, saturating soils that began to slide. Three landslides on the tributary to Swift Creek triggered three debris flows, carrying debris and sediment into Swift Creek and creating a hyper concentrated flow. By 8:30 a.m., debris appeared to have clogged the culverts where Swift Creek flows under Cedar Flats Road."[5] The clogged culverts impeded creek flow and forced the surrounding embankment under the road to wash out. By the following day, the McLane Fire Department shuttled residents who needed to move in and out on a footpath and logging road. By Thursday, the County Road Department opened a temporary one-and-a-half-mile detour route that served residents for several months until a temporary bridge was constructed. The emergency detour route construction cost nearly $135,000 and construction of the temporary and new bridge cost $891,000.

On December 3, a mudslide on Kennedy Creek Road in northwestern Thurston County destroyed the Ranch House BBQ restaurant and surrounding structures. Damage was estimated at $1 million. The owners received a $914,000 Small Business Administration loan to rebuild. Slides also caused at least two homes to be tagged as uninhabitable off Sunset Beach Road.

February 28, 2001, Nisqually Earthquake. DR-1361

The 2001 Nisqually Earthquake resulted in a landslide that wiped out the northbound lanes of U.S. Highway 101 near Mud Bay in northwest Thurston County. This landslide caused nearly

$1 million in damages. Area commuters were forced to use a 30-mile detour through the town of McCleary, causing two and one-half-mile backups through the small Grays Harbor County community.

Winter 1998 - 1999, South Puget Sound Landslides

Sixty-two inches of rain fell between November 1998 and March 1999. Several landslides occurred during this time along several south Puget Sound shorelines in north Thurston County. Landslides in Sunrise Beach, Sunset Beach, Gravelly Beach, Carlyon Beach, and Hunter Point forced many families out of their homes. County inspectors initially condemned or deemed 55 homes uninhabitable. In the end, 39 homes were condemned, and 113 properties had their values significantly reduced or zeroed by the Thurston County Assessor's Office. The northeastern corner of Carlyon Beach was the hardest hit area with thirty-seven homes declared unsafe for habitation. This landslide occurred on relatively flat to gentle sloping ground. Pencil cracks in driveways slowly expanded from inches to several feet causing slumping and subsidence, destroying the foundations of many residents' homes.

Geologists determined that the landslide – likely caused by heavy winter rains – was a reactivation of an ancient slide. The 66-acre slide caused substantial damage to the private community which maintains its own streets and water treatment system.[6]

The landslides resulted in $15 million in uninsured losses to homeowners and businesses and $9.5 million in costs to county government.[7] Despite declarations of emergency and requests for federal aid from both Thurston County and Washington State Governor Gary Locke, no Federal Disaster Declaration was issued, however Federal Small Business Administration loans were provided to some families to rebuild new homes. While some families had their mortgages dismissed, others were less fortunate.

The landslide hazard persists for the Carlyon Beach/Hunter Point area although movement has ceased. Thurston County has subsequently identified 54 parcels in this area as a designated landslide hazard area. The County's Critical Areas Ordinance prohibits substantial improvements to these properties.

February 1996, Flooding. DR 1100

On February 8, Nisqually River flooding and groundwater under heavy pressure from near record rains caused a 70-foot deep, 50-foot long, by 40-foot-wide landslide. Nearly 100 dump trucks of material disappeared into the river in the Nisqually Pines neighborhood on Thuja Avenue west of Yelm. Although no homes were destroyed, the landslide threatened area residences. Thurston County declared seven homes unsafe for occupancy.[8]

On February 10, heavy rains caused a mudslide on the steep slope below Capitol Way, just west of Carlyon Avenue. It broke two sewer lines that served nearly two-thirds of Tumwater and the Olympia Brewing Company. The mudslide also tore out 50 feet of Burlington Northern rail line. It is possible that the pipes leaked prior to heavy rains and contributed to the weakening of the slope. Before repair, the damaged pipes leaked over five million gallons of untreated wastewater into Capitol Lake. Public health notices were posted around the lake to warn residents not to touch lake waters and Tumwater residents were asked to curtail their water use until the line was repaired. Emergency repairs took nearly two weeks and cost nearly $1 million.[9]

The February floods caused nearly $2.5 million in damages to Thurston County Roads. Heavy rains triggered a landslide on a steep slope over Flumerfelt Road, southwest of Bucoda, closing the road for several months. A Burlington Northern railroad tunnel collapsed onto Durgin Road SE and a 20-foot-wide by 100-foot-deep pothole closed Old Pacific Highway just before the Nisqually River bridge.

Probability of Occurrence

Landslides occur nearly annually, with a high probability of occurrence overall for the region's planning area and for all the planning partners.

Vulnerabilities and Impacts

Impacts to People

Landslides are very dangerous. People in the direct path of a landslide could experience trauma from moving rocks, mud, or other debris and result in serious injury or death. Landslides can leave people stranded or separated from their property for prolonged periods in areas with limited road access. People who lose their homes can experience temporary or long-term displacement and housing insecurity. Loss from landslides, like other disaster events, can cause grief and mental stress. An estimated 5,732 people throughout Thurston County live in areas that are potentially at risk for landslides (Table 4.4.1).

Table 4.4.1 Thurston County Population Residing in the Potential Landslide Hazard Areas

Jurisdiction	Population	Population Exposed	% Population Exposed
Bucoda	610	0	0%
Lacey	58,180	66	0.1%
Olympia	56,370	2,434	4.3%
Rainier	2,510	12	0.5%
Tenino	2,030	3	0.1%
Tumwater	26,360	223	0.8%
Yelm	10,680	11	0.1%
Unincorporated	143,760	2,983	2.0%
Total Planning Area	300,500	5,732	1.9%

Impacts to Structures and Systems

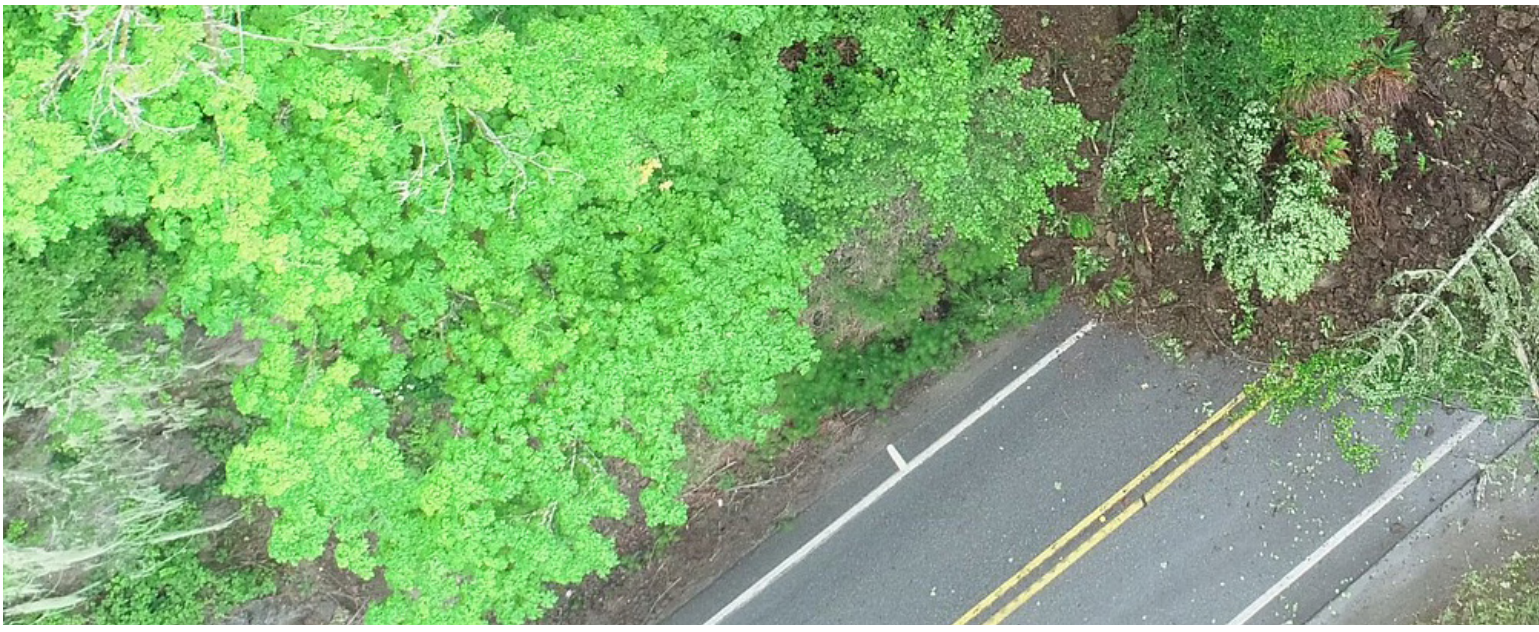
Landslides can destroy and damage structures including homes, buildings, roads, bridges, power transmission facilities, communication infrastructure, water reservoirs, sewer lines, government services, and agricultural resources. Disruptions to transportation, power, water, sewer, and communications systems can have far reaching consequences for public and private sector systems and services. There are 1,868 residential units, 179 commercial buildings, and three government facilities located in landslide hazard areas in Thurston County. In total, there are 2,050 buildings valued over $1.26 billion that are exposed to potential landslide hazard areas (Tables 4.4.2 and 4.4.3).

Table 4.4.2 Number of Structures in the Potential Landslide Hazard Areas

	Number of Structures in Landslide Hazard Areas							
Jurisdiction	Residential	Commercial	Industrial	Agriculture	Religion	Government	Education	Total
Bucoda	0	0	0	0	0	0	0	0
Lacey	20	0	0	0	0	0	0	20
Olympia	702	166	0	0	0	3	0	871
Rainier	4	0	0	0	0	0	0	4
Tenino	1	0	0	0	0	0	0	1
Tumwater	71	3	0	0	0	0	0	74
Yelm	3	0	0	0	0	0	0	3
Unincorporated	1,067	10	0	0	0	0	0	1,077
Total	**1,868**	**179**	**0**	**0**	**0**	**3**	**0**	**2,050**

Table 4.4.3 Value of Structures and Contents in the Potential Landslide Hazard Areas

Jurisdiction	Total Buildings	Total Residential Buildings	Total Building & Contents Value	Buildings Exposed	Total Building & Contents Exposed	% Total Value
Bucoda	245	237	$63,726,655	0	$0	0.0%
Lacey	18,985	17,637	$17,357,526,547	20	$9,257,909	0.1%
Olympia	18,242	16,257	$19,116,213,011	871	$775,469,886	4.1%
Rainier	875	814	$393,003,023	4	$1,483,443	0.4%
Tenino	751	651	$404,778,123	1	$387,095	0.1%
Tumwater	9,513	8,408	$9,362,171,728	74	$46,334,133	0.5%
Yelm	3,139	2,827	$2,077,637,133	3	$1,264,720	0.1%
Unincorporated	53,104	51,429	$24,765,596,428	1,077	$426,737,853	1.7%
Total Planning Area	**104,854**	**98,260**	**$73,540,652,648**	**2,050**	**$1,260,935,041**	**1.7%**



There are approximately 29 community lifeline assets that are located in potential landslide hazard areas (Table 4.4.4). Exposed assets include cellular towers and other communications transmission facilities, electric substations, potable water facilities, a wastewater lift station, a long-term residential care facility, a fire station, and several state highway bridges.

Table 4.4.4 Thurston County Community Lifelines located in the Potential Landslide Hazard Areas

Location in Planning Area	Comm-unications	Energy	Food, Water, Shelter	Hazardous Material	Health & Medical	Safety & Security	Trans-portation	Total
Bucoda	0	0	0	0	0	0	0	0
Lacey	0	0	0	0	1	0	0	1
Olympia	0	2	1	1	1	0	4	9
Rainier	0	0	0	0	0	0	0	0
Tenino	0	0	0	0	0	0	0	0
Tumwater	0	0	0	0	0	0	0	0
Yelm	0	0	0	1	0	0	0	1
Unincorporated Thurston County	8	0	2	0	0	1	7	18
Total Planning Area	**8**	**2**	**3**	**2**	**2**	**1**	**11**	**29**

Impacts to Natural, Cultural, and Historic Resources

Landslides occur in undeveloped areas along steep riverbanks and marine shorelines. Large landslides can alter the course of a river or impact fish and wildlife habitat. Loss of roads near rivers could reduce access to fishing areas. A GIS analysis of general building stock did not indicate any landslide hazard exposure for historic buildings, churches, or other structures of cultural or social significance.

Impacts to Activities

Landslides that cover or damage roads disrupt transportation. Delays in transportation impact a variety of essential and non-essential travel.

Risk Ratings

Social Vulnerability Rating and National Risk Index

Social vulnerability is the susceptibility of social groups to the adverse impacts of natural hazards, including disproportionate death, injury, loss, or disruption of livelihood. As a consequence enhancing risk component of the National Risk Index, a Social Vulnerability score and rating represent the relative level of a community's social vulnerability compared to all other communities at the same level. A community's Social Vulnerability score measures its national rank or percentile. A higher Social Vulnerability score results in a higher Risk Index score. Map 4.4.2 shows assets in Thurston County that are located in potential landslide hazard areas by census tract social vulnerability ratings.

The Federal Emergency Management Agency National Risk Index (NRI) provides a Landslide Risk Index score and rating. The rating represents a community's relative risk for landslides when compared to the rest of the United States. According to the NRI, Thurston County's landslide risk index rating is "relatively moderate." The NRI reports an estimated landslide hazard annual loss of approximately $222,675.

Community Hazard Risk Ratings for the Landslide Hazard Areas

The overall countywide landslide risk ranking score is 18 – a medium risk rating. Risk rankings vary from low to medium for most jurisdictions (Tables 4.4.5 and 4.4.6 show community and special purpose landslide hazard risk ratings). The details of the landslide hazard risk assessment calculations are shown in Appendix C.

Table 4.4.5 Community Landslide Hazard Risk Ratings

Municipal Plan Participants	Landslide Hazard Risk Ranking Score	Landslide Hazard Risk Rating
Bucoda	0	Low
Lacey	18	Medium
Olympia	18	Medium
Rainier	18	Medium
Tenino	18	Medium
Tumwater	18	Medium
Yelm	18	Medium
Unincorporated Thurston County	18	Medium
Total Planning Area	**18**	**Medium**

Table 4.4.6 Special Purpose District Landslide Hazard Risk Ratings

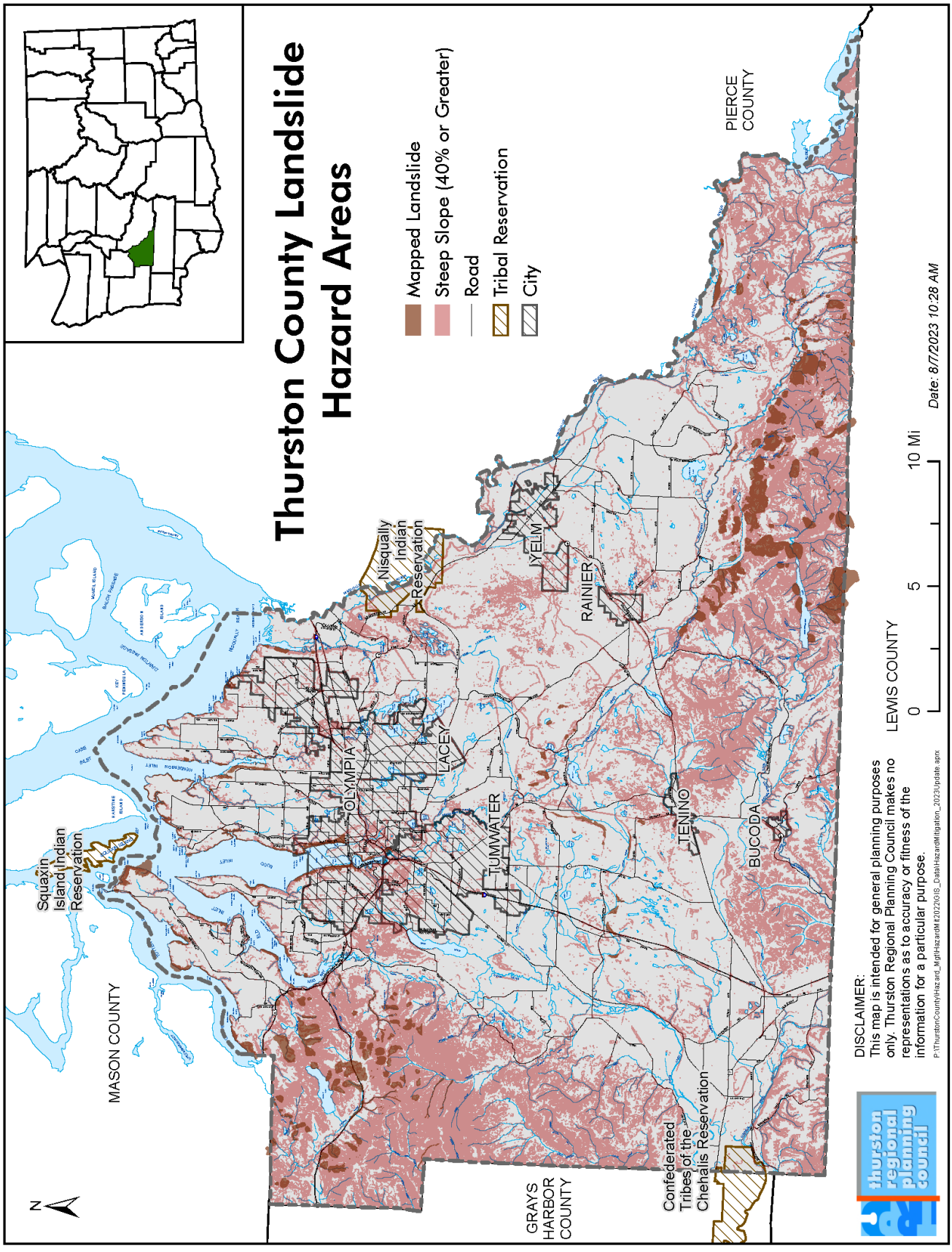
Special Purpose District Plan Participants	Landslide Hazard Risk Ranking Score	Landslide Hazard Risk Rating
East Olympia Fire District	9	Low
Intercity Transit	0	Low
Lacey Fire District	21	Medium
McLane Black Lake Fire District	9	Low
Olympia School District	0	Low
SE Thurston Fire Authority	12	Low
South Bay Fire District	9	Low
The Evergreen State College	0	Low
Thurston PUD	9	Low
West Thurston Regional Fire Authority	9	Low

Changes in Landslide Hazard Risks Since Last Plan Update

A different methodology was used to estimate hazard risks and the vulnerability of community assets since the plan was last updated. It is not possible to perform a regional assessment of any changes in landslide hazard risks since the previous plan was adopted.

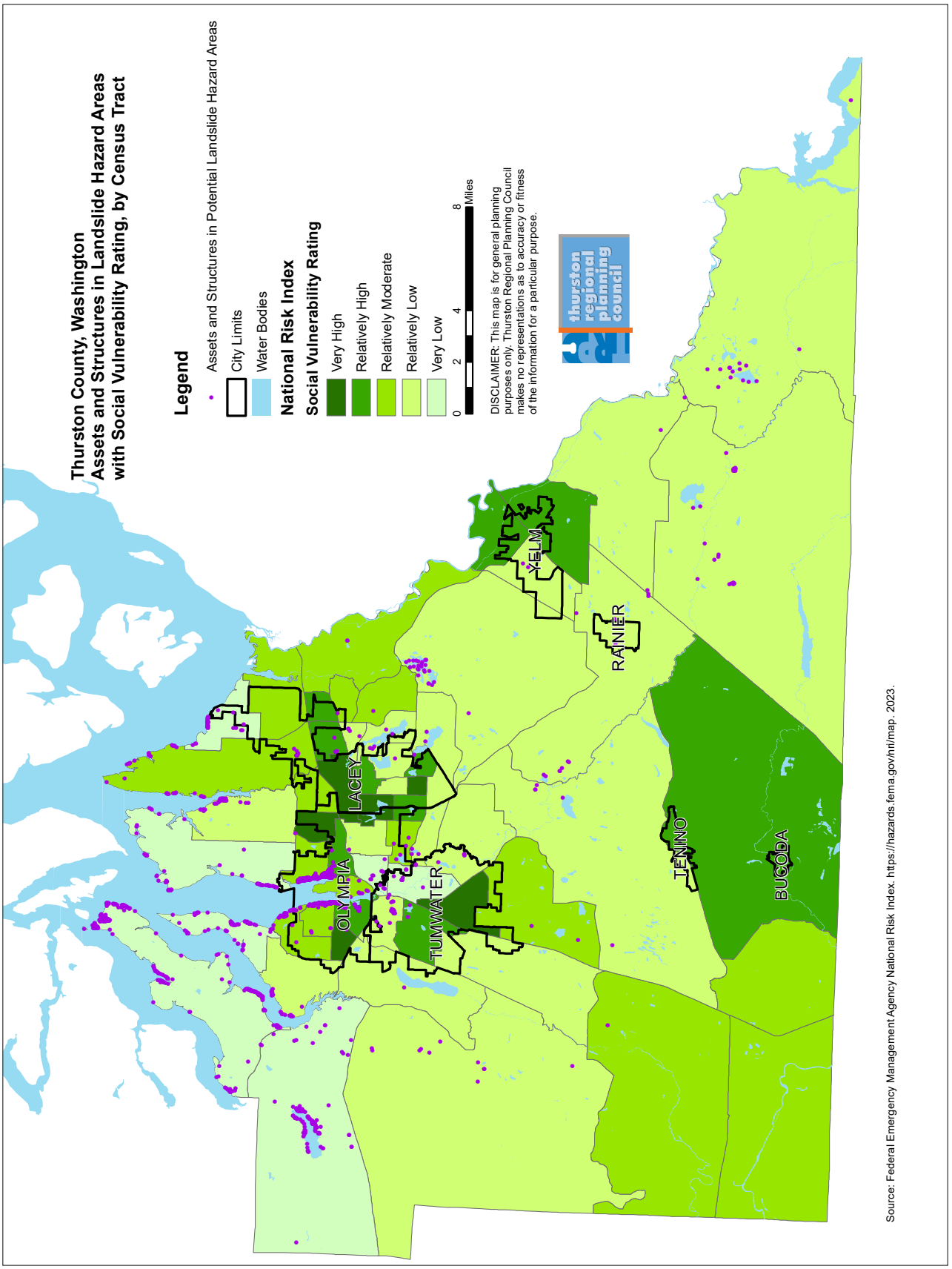
Addressing Landslide Risk in the Regional Mitigation Strategy

Local governments need more current and accurate landslide hazard mapping to improve their understanding of landslide risks. During the plan update process, the region's mitigation planning partners identified a new mitigation action to enroll in the Washington Geological Survey Landslide Hazards Program. The program will produce maps and data to assist communities with identifying landslide hazard areas, reducing potential future losses, and updating comprehensive plans, zoning codes, development regulations, and policies.



Map 4.4.1 Landslide Hazard Areas of Thurston County

Map 4.4.2 National Risk Index Landslide Annual Loss



Endnotes

[1]Michael Polentz, et al. 2008. Thurston County Marine Shore Landslides and Landforms Data. Unpublished Data. Washington Geological Survey Division on Geology and Earth Resources, Washington Department of Natural Resources.

[2]Personal Communication with Michael Polenz and Tim Walsh, Geologists, Washington Geological Survey Division on Geology and Earth Resources, Washington Department of Natural Resources. March 9, 2009.

[3]Washington State Department of Ecology. 2009 Puget Sound Landslides: Signs of Movement. http://www.ecy.wa.gov/programs/sea/landslides/signs/signs.html

[4]Ibid

[5]Washington State Department of Natural Resources. 2009. Landslide Reconnaissance Following the December 3, 2007 Storm – Thurston County.

[6]Lorrine Thompson. 2001. Struggle to Recover Continues After Slide. Published in The Olympian. February 17, 1996.

[7]Jennifer Olson. 1999. Landslide Victims Won't Get Aid. Published in The Olympian, August 27, 1999.

[8]Joel Coffidis. 1996. Nisqually Rips Yard from Homeowners. Published in The Olympian, February 17, 1996.

[9]John Dodge. 1996. Sewage Flow Into Lake Halted. Published in The Olympian, February 23, 1996.