Volume II: Hazard Annex
Landslide

Causes and Characteristics of Landslides

Landslides are a geologic hazard in almost every state in America. Nationally, landslides cause 25 to 50 deaths each year.[168] In Oregon, economic losses due to landslides for a typical year are estimated to be over $10 million.[169] In years with heavy storms, such as in 1996, losses can be an order of magnitude higher and exceed $100 million.[170] In Oregon, a significant number of locations are at risk to dangerous landslides. While not all landslides result in private property damage, many landslides impact transportation corridors, fuel and energy conduits, and communication facilities.[171] They can also pose a serious threat to human life.

A 1998 study completed by Oregon's Department of Geology and Mineral Industry (DOGAMI) states that although few landslides develop in the Willamette Valley as compared to more mountainous parts of the state, the marine sedimentary rock units near Salem and the edges of the valley are susceptible to large slides.[172]

Landslides can be broken down into two categories: (1) rapidly moving; and (2) slow moving, in addition to "on-site" or "off-site" hazards. Rapidly moving landslides are typically "off-site" (debris flows and earth flows) and present the greatest risk to human life, and persons living in or traveling through areas prone to rapidly moving landslides are at increased risk of serious injury. Rapidly moving landslides have also caused most of the recent landslide-related injuries and deaths in Oregon. A rapidly moving debris flow in Douglas County killed five people during the storms of 1996.[173] Slow moving landslides tend to be "on-site" (slumps,

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[168] Mileti, Dennis. 1999. Disasters by Design: A Reassessment of Natural Hazards in the United States. Washington D.C.: Joseph Henry Press.
[169] Wang, Yumei, Renee D. Summers, R. Jon Hofmeister, and Oregon Department of Geology and Mineral Industries. 2002. "Open-File Report O-02-05: Landslide Loss Estimation Pilot Project in Oregon." http://www.oregon.gov/LCD/docs/rulemaking/012308/item_1_Kehoe_att_b.pdf, accessed February 14, 2010
[170] Ibid.
[171] USGS Landslide Program Brochure, National Landslide Information Center, United States Geologic Survey.
[172] Harvey, Andrew F. and Gary L. Peterson. 1998. Water-Induced Landslide Hazards, Western Portion of the Salem Hills, Marion County, Oregon.
[173] DLCD & CPW. 2000. Planning for Natural Hazards: Chapter 5: Landslide TRG. http://www.oregon.gov/LCD/HAZ/docs/landslides/05_landslide.pdf, accessed May 29, 2010.

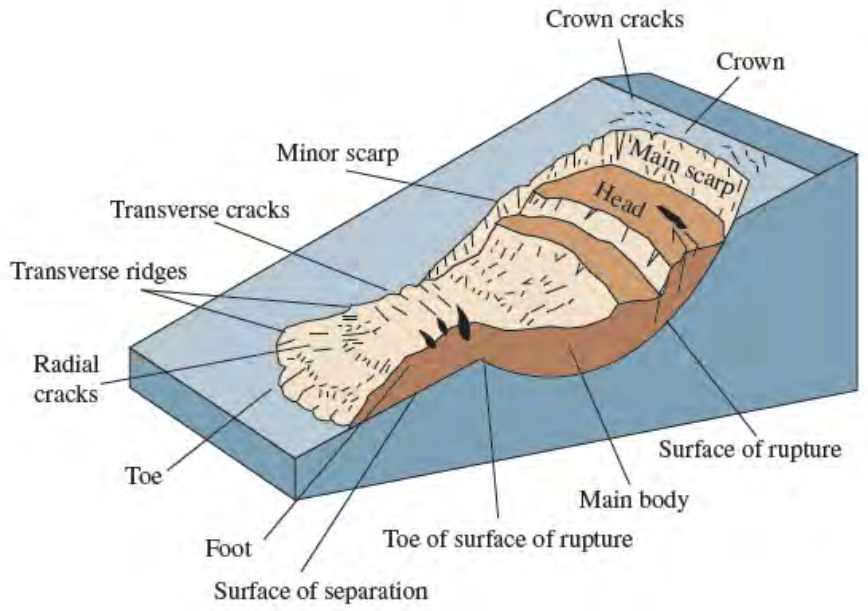
earthflows, and block slides) and can cause significant property damage, but are less likely to result in serious human injuries.

Types of Landslides

Landslides are downhill or lateral movements of rock, debris, or soil mass. The size of a landslide usually depends on the geology and the landslide triggering mechanism. Landslides initiated by rainfall tend to be smaller, while those initiated by earthquakes may be very large. Slides associated with volcanic eruptions can include as much as one cubic mile of material.

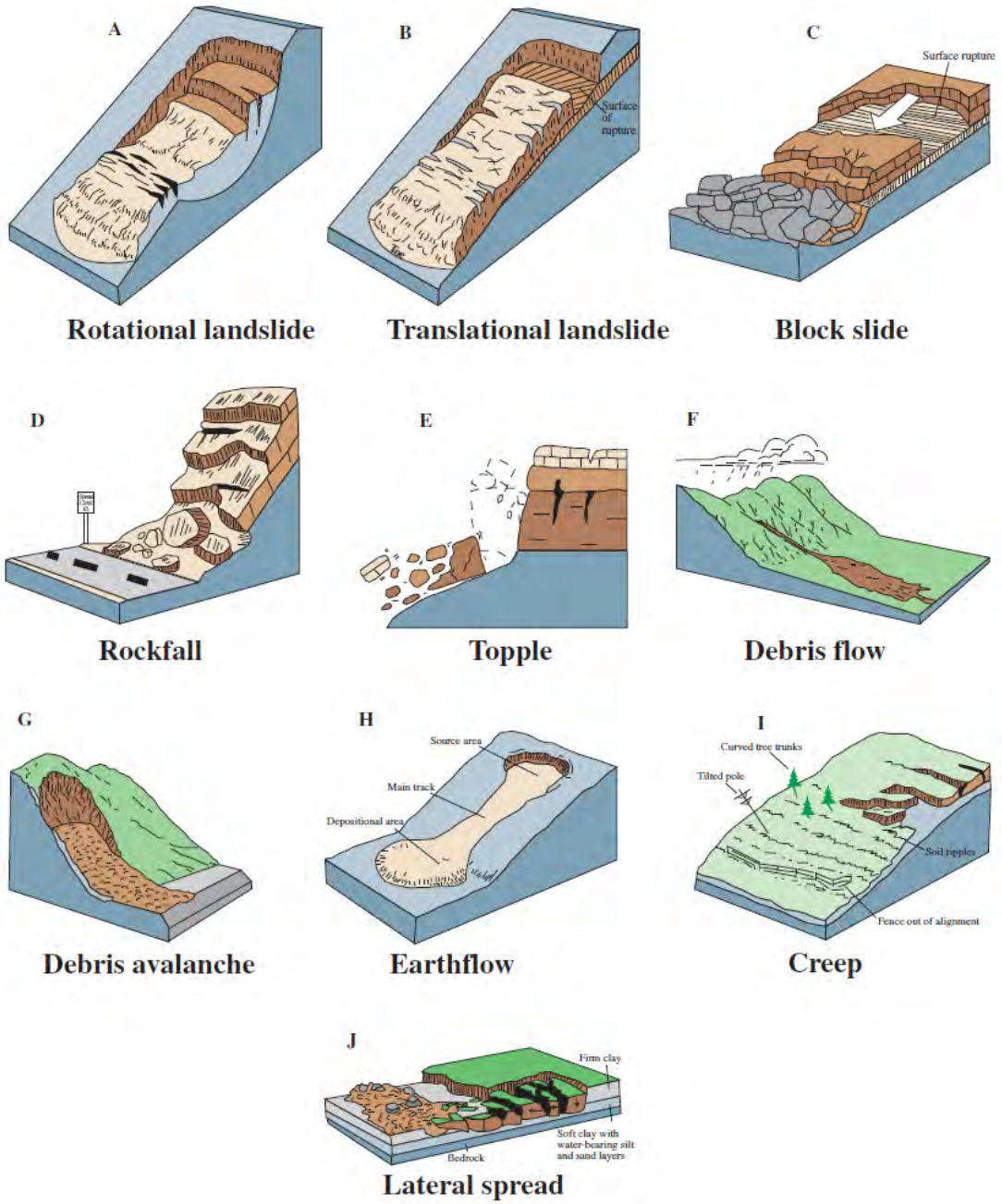
Landslides vary greatly in the volumes of rock and soil involved, the length, width, and depth of the area affected, frequency of occurrence, and speed of movement. Some characteristics that determine the type of landslide are slope of the hillside, moisture content, and the nature of the underlying materials. Landslides are given different names depending on the type of failure and their composition and characteristics. Types of landslides include slides, rock falls, and flows. Figure 1 depicts major landslide features and Figure 2 illustrates different types of landslides.

Figure 1 Landslide Features



Source: USGS. 2004. Landslide Factsheet. http://pubs.usgs.gov/fs/2004/3072/, accessed February 14, 2010

Figure 2 Landslide Types



Source: USGS. 2004. Landslide Factsheet. http://pubs.usgs.gov/fs/2004/3072/, accessed February 14, 2010.

Slides

Slides move in contact with the underlying surface. These movements include rotational slides (see Figure 3) where sliding material moves along a curved surface and translational slides (see Figure 4) where movement occurs along a flat surface. These slides are generally slow moving and can

be deep. Slow-moving landslides can occur on relatively gentle slopes and can cause significant property damage, but are far less likely to result in serious injuries than rapidly moving landslides.[174]

Figure 3 Rotational Slide

Source: DOGAMI. 2008. Oregon Geology Fact Sheet: Landslide Hazards in Oregon. http://www.oregongeology.org/sub/publications/landslide-factsheet.pdf, accessed February 11, 2010

Figure 4 Translational Slide

Source: DOGAMI. 2008. Oregon Geology Fact Sheet: Landslide Hazards in Oregon. http://www.oregongeology.org/sub/publications/landslide-factsheet.pdf, accessed February 11, 2010

Erosion

Erosion occurs when ditches or culverts beneath hillside roads become blocked with debris. If the ditches are blocked, run-off from the slopes is inhibited during periods of precipitation. This causes the run-off water to collect in soil, and in some cases, cause a slide. Usually the slides are small (100 – 1,000 cubic yards), but they can be quite large.

[174] Interagency Hazard Mitigation Team. 2000. State Hazard Mitigation Plan. Oregon State Police – Office of Emergency Management.

Rock Falls

Rock falls occur when blocks of material come loose on steep slopes. Weathering, erosion, or excavations, such as those along highways, can cause falls where the road has been cut through bedrock. They are fast moving with the materials free falling or bouncing down the slope. In falls, material is detached from a steep slope or cliff. The volume of material involved is generally small, but large boulders or blocks of rock can cause significant damage. Rock falls have the potential to break off power poles located on hillsides.[175]

Flows

Plastic or liquid movements in which land mass (e.g. soil and rock) breaks up and flows during movement. Earthquakes often trigger flows.[176] Debris flows normally occur when a landslide moves downslope as a semi-fluid mass scouring, or partially scouring soils from the slope along its path. Flows are typically rapidly moving and also tend to increase in volume as they scour out the channel.[177] Flows often occur during heavy rainfall, can occur on gentle slopes, and can move rapidly for large distances.

Conditions Affecting Landslides

Natural conditions and human activities can both play a role in causing landslides. Certain geologic formations are more susceptible to landslides than others. Locations with steep slopes are at the greatest risk of slides. However, the incidence of landslides and their impact on people and property can be accelerated by development. Developers who are uninformed about geologic conditions and processes may create conditions that can increase the risk of or even trigger landslides.

There are four principal factors that affect or increase the likelihood of landslides:

- Natural conditions and processes including the geology of the site, rainfall, wave and water action, seismic tremors and earthquakes and volcanic activity.
- Excavation and grading on sloping ground for homes, roads and other structures.
- Drainage and groundwater alterations that are natural or human-caused can trigger landslides. Human activities that may cause slides include broken or leaking water or sewer lines, water retention facilities, irrigation and stream alterations,

[175] Eichorn, Ernie. Field Representative, Chemawa District, Bonneville Power Authority. Personal Interview. 10 November 2004.
[176] Robert Olson Associates. June 1999. Metro Regional Hazard Mitigation Policy and Planning Guide. Portland, OR: Metro.
[177] Ibid.

ineffective storm water management and excess runoff due to increased impervious surfaces.

- Change or removal of vegetation on very steep slopes due to timber harvesting, land clearing and wildfire.

History of Landslides in Marion County

A 1998 study of the western portion of the Salem Hills completed by the Department of Geology and Mineral Industries (DOGAMI) indicates that slopes nearest to the Willamette River contain the greatest risk of landslide in Marion County.[178] This area is near a dense population and poses significant risks to life and property. While no recent landslides have occurred in the area, the geologic setting of the Salem Hills illustrates a historic pattern of landslides. Many prominent features that help identify the ancient landslide terrain are hummocky topography, disrupted drainage patterns, sag ponds, springs, back-tilted bedrock blocks, and subdued head scarps.[179]

In the southeastern portion of the county, the Little North Fork Road experiences annual landslide events. The hillside where Highway 22 narrows near Mill City sloughs off three or four times a year, closing the highway for up to three hours until the Oregon Department of Transportation (ODOT) can clear the road of debris.[180]

In February 1996, November 1996, and December 1996/January 1997 the Willamette Valley experienced heavy rainfall and snowmelt which led to widespread landslide events throughout the state. Disaster declarations were issued for Marion County for the February 1996 and December 1996/January 1997 storms.[181] During these storms, many landslides occurred in the eastern portion of the state, and are too numerous to list here. In 2000, DOGAMI mapped the historical instances of landslide events throughout the Willamette Valley for the 1996-1997 storms, including Marion County, which is depicted in Figure 5 below.

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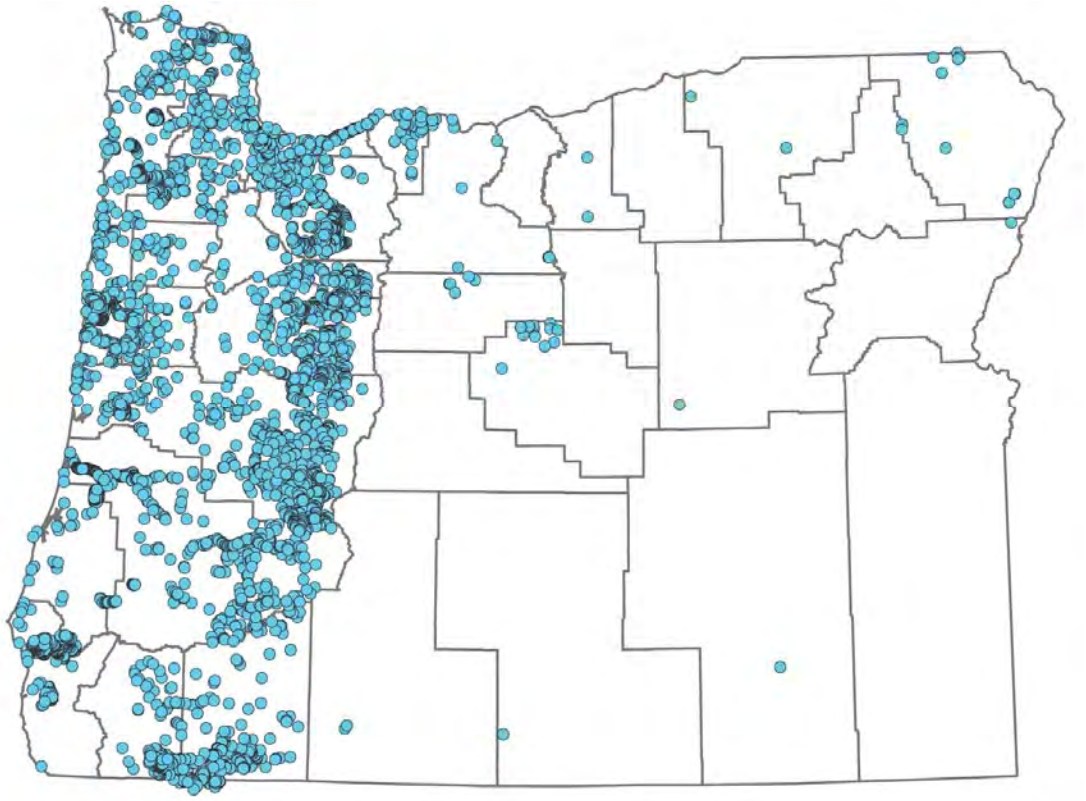
[178] Harvey, Andrew F. and Gary L. Peterson. 1998. Water-Induced Landslide Hazards, Western Portion of the Salem Hills, Marion County, Oregon.
[179] Harvey, Andrew F. and Gary L. Peterson. 1998. Water-Induced Landslide Hazards, Western Portion of the Salem Hills, Marion County, Oregon.
[180] Nevins, Dan. BLM Road Engineer, Cascades Resource Area. Personal Interview. 16 December 2004.
[181] Oregon State Archives, Governor's Executive Orders, *EO-96-12, EO-97-9,* http://arcweb.sos.state.or.us/governors/Kitzhaber/web_pages/governor/legal/execords.htm, accessed September 28, 2010.

Figure 5. Map of the over 9,500 landslides from DOGAMI *Special Paper 34, Slope Failures in Oregon*, 2000



Source: Hofmeister, *Special Paper 34: Slope Failures in Oregon*, DOGAMI, 2000, accessed from the United States Geological Survey, http://landslides.usgs.gov/regional/inventory/oregon/, September 28, 2010.

Risk Assessment

How are Hazard Areas Identified?

Geologic and geographic factors are important in identifying landslide-prone areas. Stream channels, for example, have major influences on landslides, due to undercutting of slopes by stream erosion and long-term hillside processes.

The Oregon Department of Forestry (ODF) Storm Impacts Study conducted after the 1996-97 landslide events found that the highest probability for the initiation of shallow, rapidly moving landslides was on slopes of 70 to 80 percent steepness. A moderate hazard of shallow rapid landslide initiation can exist on slopes between 50 and 70 percent.[182]

[182] Storm Impacts and Landslides of 1996 Final Report. (1999) Oregon Department of Forestry.

In general, areas at risk to landslides have steep slopes (25 percent or greater,) or a history of nearby landslides. In otherwise gently sloped areas, landslides can occur along steep river and creek banks, and along ocean bluff faces. At natural slopes under 30 percent, most landslide hazards are related to excavation and drainage practices, or the reactivation of preexisting landslide hazards.[183]

The location of the landslide hazard for Marion County is depicted in Figures 6-8 below. Figure 6 shows the debris flow hazard areas for Marion County based on data from the Oregon Department of Forestry (ODF). Figure 7 shows landslide hazard areas for Marion County. Figure 8 depicts slide hazards in the Salem Hills. These figures indicate that there are three major areas containing slide hazards: the western portion of the Salem Hills, the southeastern portion of the county (north of the Santiam River), and slopes located southeast of Scotts Mills.

The severity or extent of landslides is typically a function of geology and the landslide triggering mechanism. Rainfall initiated landslides tend to be smaller, and earthquake induced landslides may be very large. Even small slides can cause property damage, result in injuries, or take lives.

[183] State Hazard Mitigation Plan. The Interagency Hazards Mitigation Team, (2000) Oregon State Police - Office of Emergency Management.

Figure 6 Debris Flow Hazard in Marion County

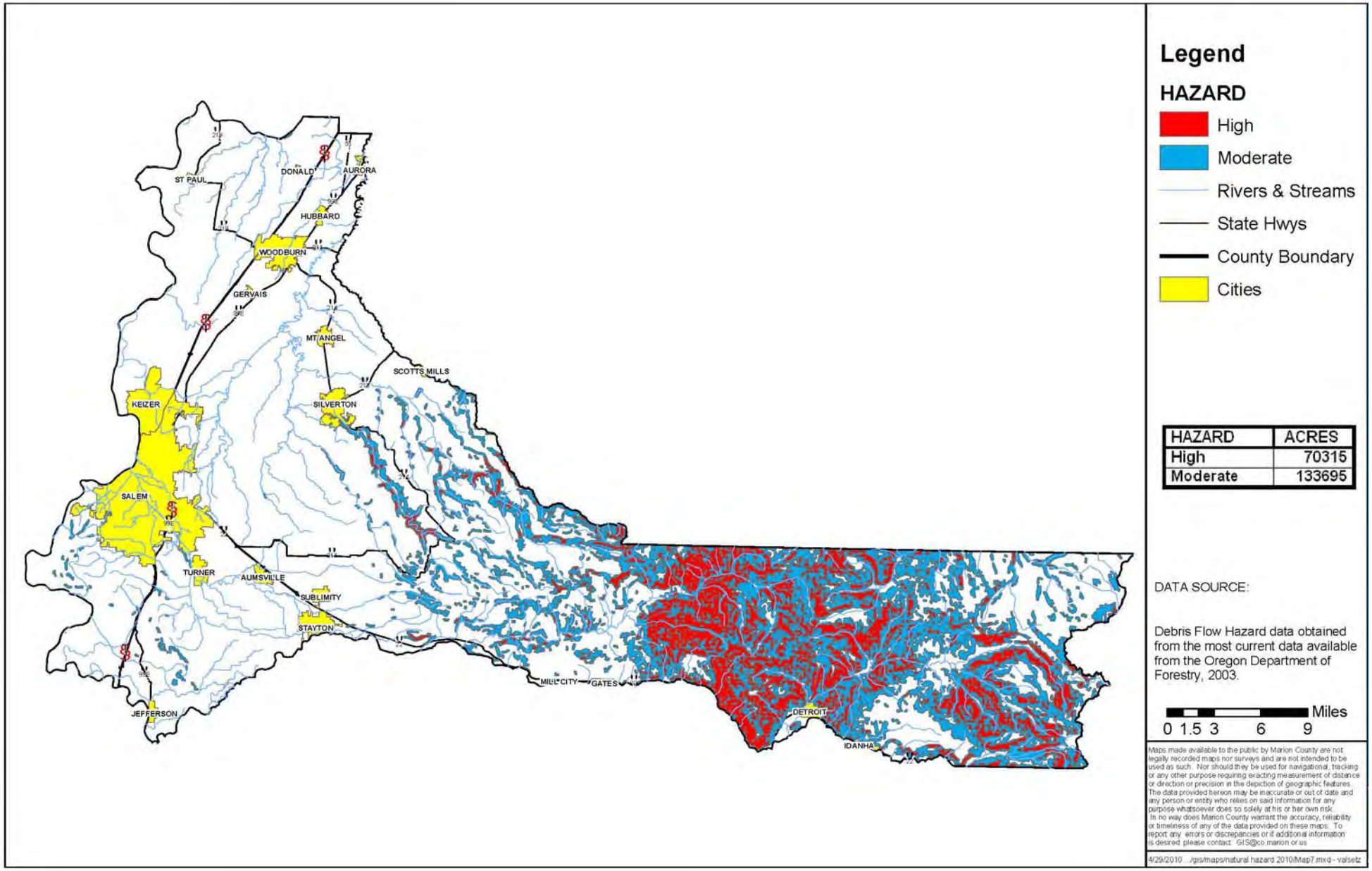


Figure 7 Landslide Hazard in Marion County

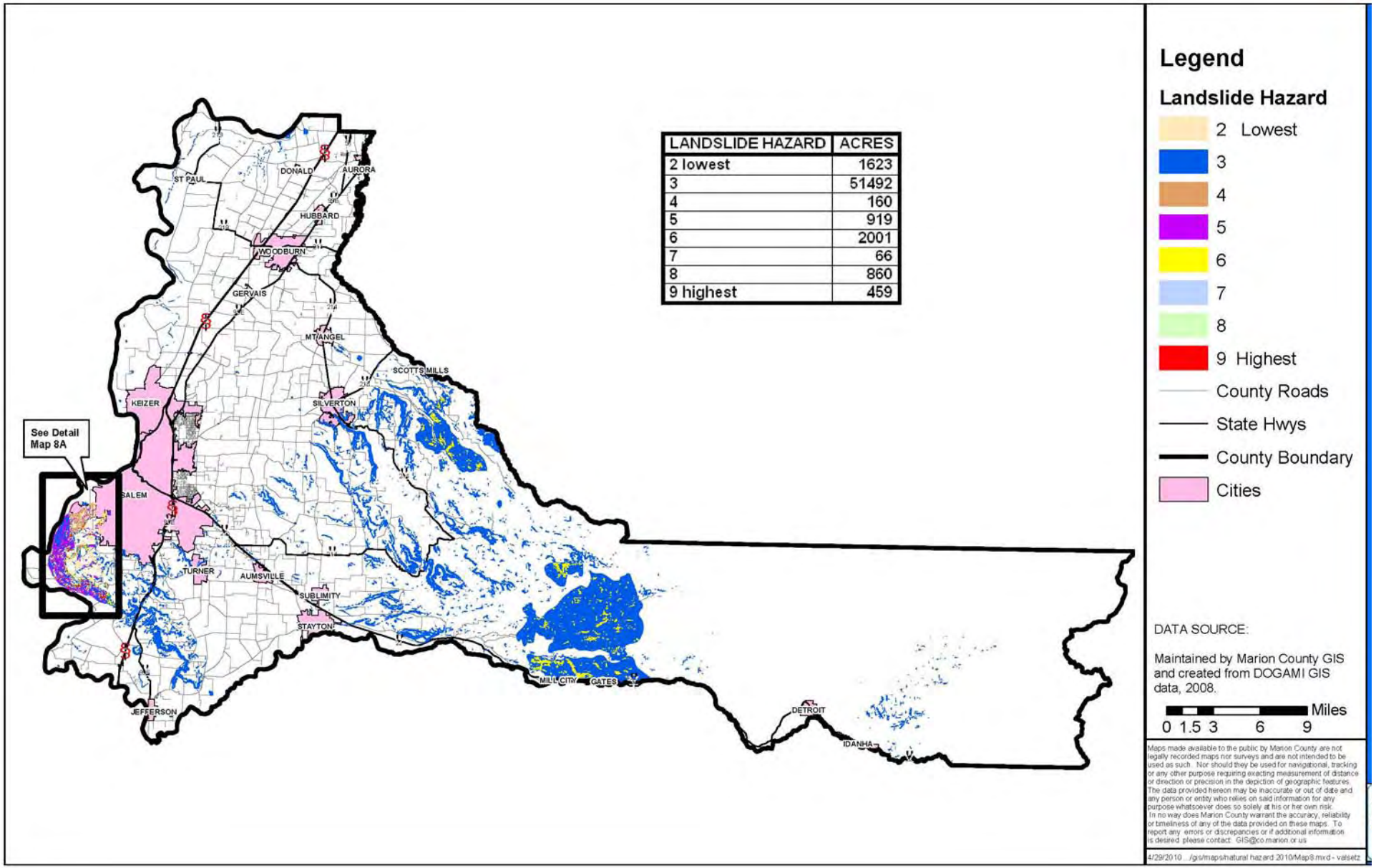
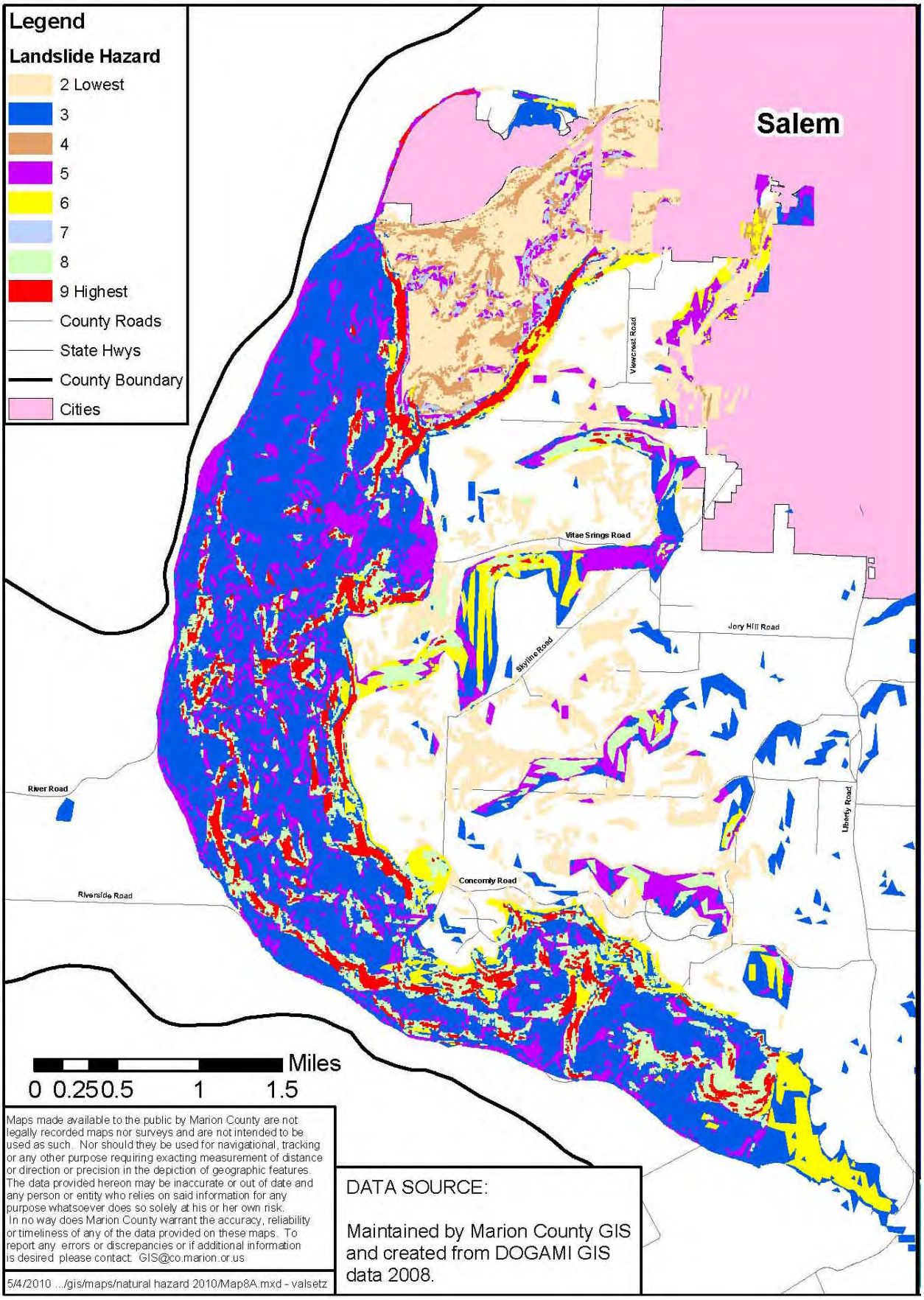


Figure 8 Landslide Hazard Issues In South Salem Hills



Probability of Future Occurrence

The probability of rapidly moving landslide occurring depends on a number of factors, including steepness of slope, slope materials, local geology, vegetative cover, human activity, and water. There is a strong correlation between intensive winter rainstorms and the occurrence of rapidly moving landslides (debris flows). Consequently, the Oregon Department of Forestry tracks storms during the rainy season, monitors rain gauges and snow melt, and issues warnings as conditions warrant. Given the correlation between precipitation, snow melt, and rapidly moving landslides, it would be feasible to construct a probability curve. The installation of slope indicators or the use of more advanced measuring techniques could provide information on slower moving slides.

Geo-engineers with the Oregon Department of Forestry (ODF) estimate widespread landslides about every 20 years; landslides at a local level can be expected every two or three years.[184]

The 2006 Marion County Hazard Analysis did not rate the probability of a landslide occurring. Based on Marion County's landslide history, the Marion County steering committee determined that the probability of a landslide occurring is **high**, meaning that one event is likely in a 10-35 year period.

Vulnerability Assessment

To a large degree, landslides are very difficult to predict. Vulnerability assessments assist in predicting how different types of property and population groups will be affected by a hazard.[185] The optimum method for doing this analysis at the county or jurisdiction level is to use parcel-specific assessment data on land use and structures. [186] Data that includes specific landslide-prone and debris flow locations in the county can be used to assess the population and total value of property at risk from future landslide occurrences.

While a quantitative vulnerability assessment (an assessment that describes number of lives or amount of property exposed to the hazard) has not yet been conducted for Marion County landslide events, there are many qualitative factors (issues relating to what is in danger within a community) that point to potential vulnerability. Landslides can impact major transportation arteries, blocking residents from essential services and businesses. While past landslide events have not caused major property damage or significantly impacted county residents, continuing to

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[184]Mills, K. 2002. Oregon's Debris Flow Warning System. *Cordilleran Section–98th Annual Meeting*. Corvallis.

[185] Burby, R., ed. 1998. Cooperating with Nature. Washington D.C.: Joseph Henry Press.

[186] Burby, R., ed. 1998. Cooperating with Nature. Washington D.C.: Joseph Henry Press.

map county landslide and debris flow areas will help in preventing future loss.

The 2006 Marion County Hazard Analysis did not rate Marion County's vulnerability to landslides. The Marion County steering committee determined Marion County has a **moderate** vulnerability to landslides. A moderate rating means that 1-10% of the population or regional assets would be impacted by a landslide. Many aspects of the county are vulnerable to landslides. This includes land use and development patterns, the economy, population segments, ecosystem services, and cultural assets. The impacts to these community sectors are described in more detail in the hazard impacts section below.

Risk Analysis

A risk analysis estimating the potential loss of life and property for the landslide hazard in Marion County has not been completed at this time. However, given the county's high probability of landslides occurring, a risk analysis should be completed when data is available (see Multi-Hazard Action # 8).

Community Hazard Issues

What is susceptible to damage during a hazard event?

Depending upon the type, location, severity and area affected, severe property damage, injuries and loss of life can be caused by landslide hazards. Landslides can damage or temporarily disrupt utility services, roads and other transportation systems and critical lifeline services such as police, fire, medical, utility and communication systems, and emergency response. In additional to the immediate damage and loss of services, serious disruption of roads, infrastructure and critical facilities and services may also have longer term impacts on the economy of the community and surrounding area.

Increasing the risk to people and property from the effects of landslides are the following five factors:

- Improper excavation practices, sometimes aggravated by drainage issues, can reduce the stability of otherwise stable slopes.
- Allowing development on or adjacent to existing landslides or known landslide-prone areas raises the risk of future slides regardless of excavation and drainage practices. Homeowners and developers should understand that in many potential landslide settings there are no development practices that can completely assure slope stability from future slide events.
- Building on fairly gentle slopes can still be subject to landslides that begin a long distance away from the development. Sites at greatest risk are those situated against the base of very steep slopes, in

confined stream channels (small canyons), and on fans (rises) at the mouth of these confined channels. Home siting practices do not cause these landslides, but rather put residents and property at risk of landslide impacts. In these cases, the simplest way to avoid such potential effects is to locate development out of the impact area, or construct debris flow diversions for the structures that are at risk.

- Certain forest practices can contribute to increased risk of landslides. Forest practices may alter the physical landscape and its vegetation, which can affect the stability of steep slopes. Physical alterations can include slope steepening, slope-water effects, and changes in soil strength. Of all forest management activities, roads have the greatest effects on slope stability, although changing road construction and maintenance practices are reducing the effects of forest roads on landslides.

- High rainfall accumulation in a short period of time increases the probability of landslide. An extreme winter storm can produce up to 6 inches of rainfall in a 24 hour period; if the storm occurs well into the winter season, when the ground is already saturated, the hydraulic overload effect is heightened.

Marion County communities that are at risk to landslides include the city of Scotts Mills, the western portion of Salem Hills, and the southeastern portion of the county (north of the Santiam River). Further areas at risk in Salem are in the south off of Liberty and River Roads, where there has been clearing of vegetation on steep slopes for new developments.

Critical facilities and infrastructure at risk to landslides in Marion County include Highway 22 and North Fork Road, which have the potential to isolate communities from the rest of the county. This is especially true for residents of Elkhorn, whose main access road is the North Fork Road. The North Fork Road has a history of continual slides and efforts to stabilize the roadway are ongoing. Landslides on the Detroit bridge can isolate communities such as Detroit and Breitenbush. Landslides may also affect drinking water facilities, particularly should one occur by or in the Santiam River. This would increase river sedimentation, which has the potential to clog the water purifying systems used for drinking water. Should this occur it would have major implications for communities that are reliant on the Santiam as their source of drinking water, which may result in a system shut off and reduced if any availability of drinking water.

Environmental assets at risk of landslides include the Santiam River, Detroit Lake, and forestlands. Water sources such as the Santiam River and Detroit Lake, and forestlands in Marion County are linked to the local economy as they provide drinking water, recreational opportunities, and timber. Should access to these natural assets become blocked by landslides this may affect the local economy.

Certain cultural assets that are linked to the region's identity and economy are also vulnerable to landslide events. The steering committee identified these cultural assets as Breitenbush hot springs, Opal Creek Mining Camp, Silver Falls State Park, and the Detroit and Big Cliff Dams. All these assets are tourist draws that provide recreational opportunities for the public.

Existing Hazard Mitigation Activities

Landslide Hazard Study

Through FEMA's Hazard Mitigation Grant Program, Marion County, City of Salem, and DOGAMI received $250,000 and collaborated on a landslide hazard study project (1998-2000). This project was recognized and nominated for the 2003-2004 Partners for Disaster Resistance and Resilience, Oregon Showcase State Exemplary Natural Hazard Mitigation Project for its unique landslide and geohazard ordinances. The landslide hazard study and implementing landslide hazard ordinances demonstrate that jurisdictions, by actively involving citizenry and using GIS, can collaborate to reduce the risk from geologic hazards on a local and regional scale.

The landslide hazard study scope of work identified the nature and causes of landslides, established hillside development regulations, and documented the activities and decision process. Marion County incorporated landslide data from the various sources utilized as inventory information for the geological hazards ordinance (see below), along with excessive slope information i.e., slopes in excess of 20 percent as data layers in the county's GIS. The point system to determine the level of geological review that is needed under the ordinance has been incorporated into the county zone maps making it easier for staff and property owners to determine the relative risk with regard to various hazard areas of a property. The information is available and viewable by the public and used as a toll in discussing development options for property owners whose parcels contain identified geological hazard areas.

County Zoning Ordinance

In 2002, Marion County began implementing the "Geologically Hazardous Areas Overlay Zone" chapter (Chapter 182) in its Zoning Ordinance, now known as Chapter 24 in the "Geologically Hazardous Areas Overlay Zone."[187] This chapter implements the Development Limitations goal and policies of the Rural Development Section of the Marion County Comprehensive Land Use Plan, and Statewide Land Use Planning Goal 7 – Areas Subject to Natural Disasters and Hazards. This chapter applies to the entire county. Chapter 182 implements the strategy for reviewing development applications for properties within identified slide hazard and

[187] Marion County Oregon. 2010. Geologically Hazardous Areas Overlay Zone: Chapter 24. http://www.co.marion.or.us/PW/Planning/zoning/geohazard/chapter24.htm, accessed May 30, 2010.

excessive slope areas to address the risk that a proposed land use activity may adversely affect the stability and landslide susceptibility of an area.

The percentage of vacant land in landslide areas underscores the necessity of developing landslide hazard mitigation activities. The potential for future development necessitates strong regulations to reduce risk from potential landslide events. The provisions of Chapter 182 are intended to manage the risk of a landslide within identified slide hazard and excessive slope areas by requiring geological and geotechnical reports, but not act as a guarantee that the landslide hazard risk will be eliminated. Chapter 182 requires that an appropriate level of study occur before development occurs.

Relative Landslide Risk Maps

The county has developed maps that indicate the location of areas susceptible to landslides, areas of known landslide hazards, and excessive slope areas. These maps are based on the best available information and may be amended based upon receipt of corrected, updated or refined data, or upon the revision of studies upon which the maps were initially based.

Hazard Mitigation Action Items

The following actions have been identified by the Marion County steering committee, and are recommended for mitigating the potential effects of landslides in Marion County. Please see full action item worksheets in Appendix A.

Landslide Action Items

LS1: Increase monitoring and evaluation of steep slopes around Marion County's most heavily traveled roads and continue monitoring of all forested slopes cleared for housing developments.

LS2: Repair ongoing slide problems on the Little North Fork River and Abiqua Creek areas.