STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
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Water-Induced Landslide Hazards, Eastern Portion of the Eola Hills, Polk County, Oregon

2000

IMS-5

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By A.F. Harvey and G.L. Peterson

Funded by the Hazard Mitigation Grant Program
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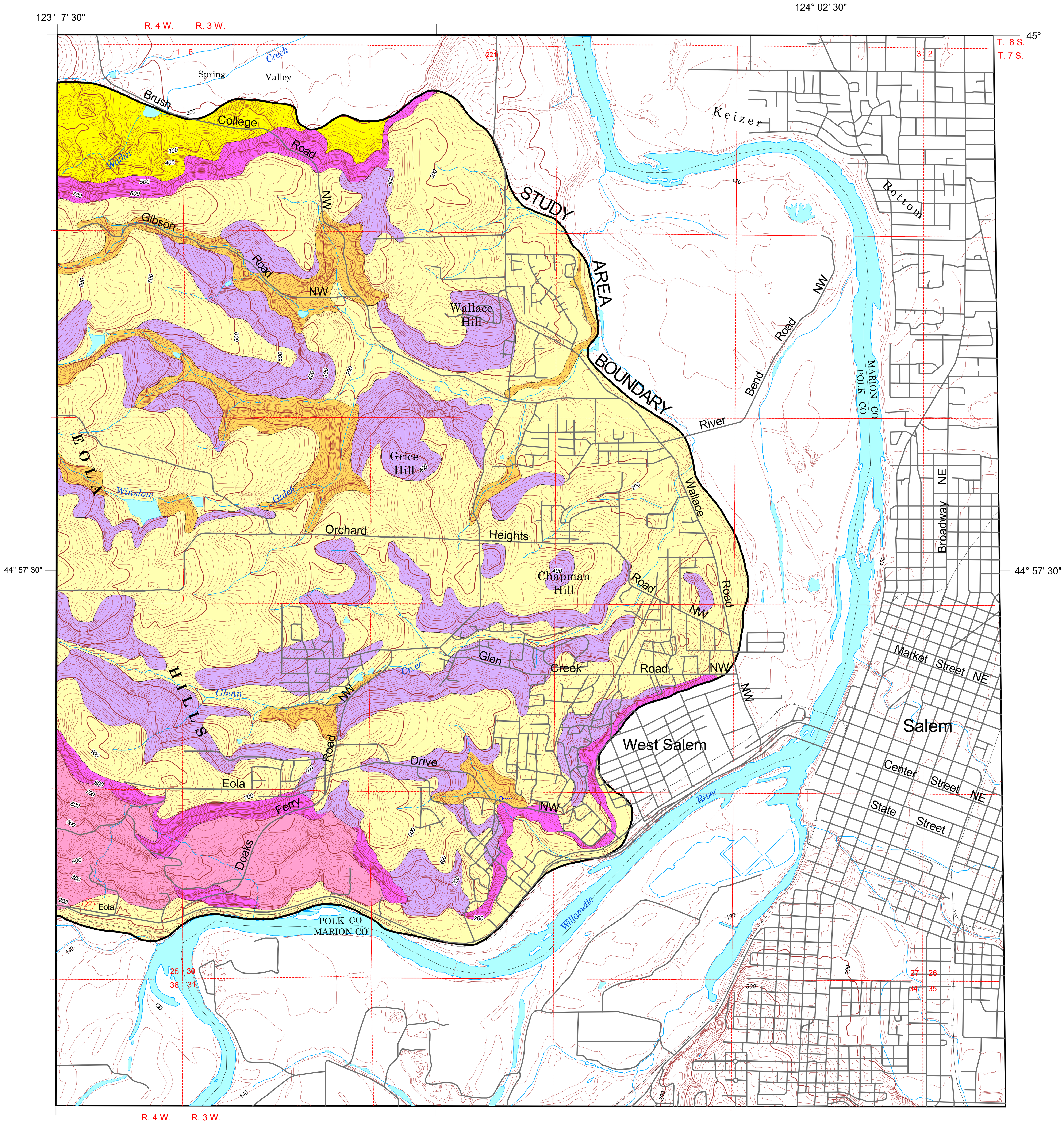


Rating Categories of Water-Induced Landslide Susceptibility

The susceptibility categories represent the nature and relative degree of hazard for water-induced landslides and related slope failures in the study area. The categories are ranked, with Category 6 representing the greatest overall hazard and Category 1 the least hazard, although the specific type of landslide hazard varies between the areas. The categories were defined according to the relative age and apparent degree of landslide activity as disclosed by topographic expression, known historic ground instability, slope steepness, geologic setting, and slope drainage. Earthquake-induced hazards are not addressed. The accompanying text further describes each of the categories.

Category	Susceptibility rating and explanation
6	High susceptibility to local landslides, debris flows, and rockfalls along steep escarpments under adverse surface water and ground water conditions.
5a	High susceptibility to localized ground movement. Located within an area displaying localized slope instability and poor drainage.
4	High susceptibility to ground movement, when disturbed by development, on slopes of 15% and greater where clay soils overlie basalt bedrock. General areas shown are sensitive to changes in surface water and groundwater drainage and infiltration.
3	Moderate susceptibility to debris flows, rockfalls, and localized landslides along steep drainage slopes.
2	Generally low susceptibility to ground movement. Located within a dormant mature landslide mass with generally good drainage.
1	Generally low susceptibility to landslides in upland areas on slopes less than 15%. An elevated risk of slope failure is not apparent.

Recommendations for Geotechnical Investigation Level and Risk Reduction, by Susceptibility Category as shown

Map category	Landslide hazard rating	Special geology and slope conditions	Level and Type of Geotechnical Investigation Recommended	Water-Induced Landslide Risk-Reduction Options
6	High	Steep escarpments in bedrock and soil; known rockfalls, landslides, debris flows	Level: Detailed Type: Subdivision and Site-specific Engineering Geology and Geotechnical Engineering reports	Restrict development and encourage use as undeveloped land and natural open space
5a	High	Some active ground movement; most slopes over 15%; localized poor drainage conditions	Level: Detailed Type: Subdivision and Site-specific Engineering Geology and Geotechnical Engineering reports	Restrictions on allowable development density; when building roads and structures, control surface water drainage; minimize earthwork; use of natural open space on critical slopes and drainage ways
4	High	Clay soils overlying weathered basalt bedrock on slopes of 15% and greater; soil and weak rock sensitive to changes in slope, surface water and groundwater conditions	Level: Detailed Type: Subdivision and Site-specific Engineering Geology and Geotechnical Engineering reports	Restrictions on allowable development density; when building roads and structures, control surface water drainage; minimize earthwork; use of natural open space on critical slopes and drainage ways
3	Moderate	Oversteepened slopes; stream erosion; potential debris flows and slope failures	Level: Detailed Type: Subdivision and Site-specific Engineering Geology and Geotechnical Engineering reports	Restrictions on allowable development density and location; when building roads and structures, control surface water drainage
2	Low	Some slopes over 15%; some debris flows and slope failures	Level: Reconnaissance Type: Subdivision Engineering Geology report; Site-specific Engineering Geology and Geotechnical Engineering reports for slopes of 15% and greater	When building roads and structures, control surface water drainage; minimize earthworks; use of natural open space on critical slopes and drainage ways
1	Low	Some slopes over 15%; extensive clay soils over weathered basalt bedrock	Level: Reconnaissance Type: Subdivision Engineering Geology Report; Site-specific Engineering Geology and Geotechnical Engineering Reports for slopes of 15% and greater	Normal construction and grading standards on land with slopes less than 15%; special standards on slopes of 15% and greater to control drainage

Please note:
Information provided in this publication should NOT be used in place of subdivision or site-specific engineering geologic studies. The relative water-induced landslide hazard categories are not intended to replace site-specific or subdivision evaluations, such as for engineering analysis and design. Refer to DOGAMI publication GMS-105 for information on earthquake-induced landslide hazards. Subdivisions or site-specific landslide hazards should be addressed through engineering geology investigations by qualified professionals properly licensed to practice in the State of Oregon.

Base map derived from U.S. Geological Survey,
Salem West, OR 7.5' quadrangle
The quadrangle was scanned and converted to vector files by the Engineering Support Unit of the Oregon Department of Corrections

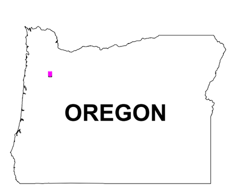
Oregon State Plane Coordinate System, north zone, NAD 27

N

Scale 1:24,000

0 ½ 1 Mile

Contour interval 10 feet



Location Map

By Andrew F. Harvey and Gary L. Peterson,
Squier Associates, Lake Oswego, Oregon
for the Oregon Department of Geology and Mineral Industries

This map is available from:

The Nature of the Northwest Information Center
800 NE Oregon Street #5
Portland, OR 97232
503/872-2750 www.naturenw.org
and the Baker City and Grants Pass, Oregon field offices
of the Oregon Department of Geology and Mineral Industries

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Interpretive Map Series

IMS-5

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Text

IMPORTANT NOTICE

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Interpretive Map Series

IMS-5

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by Andrew F. Harvey and Gary L. Peterson, Squier Associates, Lake Oswego, Oregon

INTRODUCTION

The text and map of this report identify and characterize the nature and degree of water-induced landslide hazards in a portion of the Eola Hills of Polk County, Oregon. The study is based upon existing geologic mapping, limited field reconnaissance mapping, and other available data. The study area occupies portions of the upland region and the north, east, and south slopes of the Eola Hills, located west of the Willamette River, and the incorporated area of West Salem (Figure 1). Portions of the U.S. Geological Survey (USGS) 7½-minute Salem West quadrangle are included within the study area. The south and north slopes of the study area consist, partially, of ancient landslide masses that exhibit recurrent, localized movement. The Eola Hills are currently experiencing increased suburban development pressures as a result of increasing population growth in the mid-Willamette Valley.

The map depicts categories of susceptibility to ground movement initiated by mechanisms related to surface water and groundwater. Also included on the map are recommendations pertaining to appropriate geologic and geotechnical investigations and risk re-

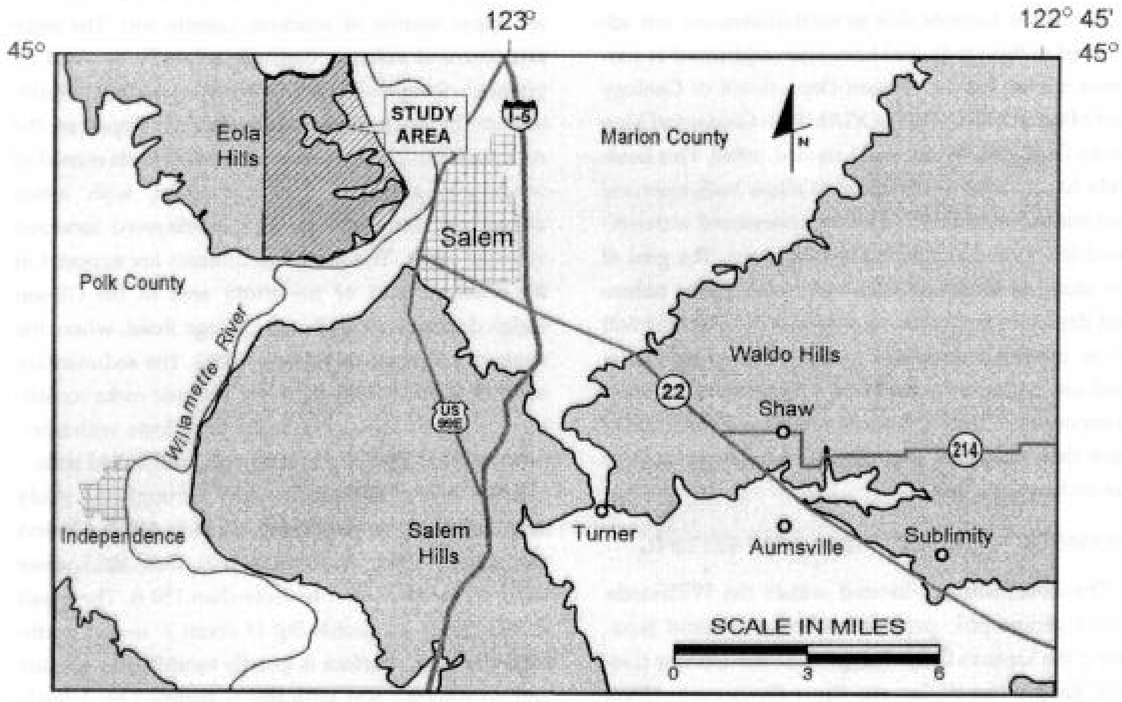

Figure 1. Sketch map showing location of study area (cross-hatched). Features are for illustrative purposes only and are approximate.

duction options for the various categories of landslide susceptibility. The primary objective of the *Landslide Hazard Map* is to provide local governmental jurisdictions, planners, developers, consultants, and the public with a tool that identifies the types of hazard present in a given area and suggests appropriate risk reduction options for consideration in any proposed development or land use consideration.

A hierarchical system of relative susceptibility is presented on the map, with categories ranging from low (Category 1) to high (Category 6). Areas with the highest susceptibility have the greatest hazard of landslides and associated types of ground movement such as debris flows and rock falls. These areas of high susceptibility are most likely to suffer the most numerous and large-scale slope movements under natural conditions and have the highest potential for ground movement due to man-made disturbance. Those areas with the lowest susceptibility are likely to have the least landslide occurrences under natural conditions and are relatively less sensitive to man-made disturbance.

Landslide hazards due to earthquakes are not addressed in this study, but have been addressed in previous studies by the Oregon Department of Geology and Mineral Industries (DOGAMI), in Geological Map Series GMS–105 (Wang and Leonard, 1996). This landslide hazard map is designed to allow both technical and nontechnical users to better understand water-related landslide hazards in the study area. The goal of the study is to characterize variations in the nature and degree of landslide hazards in a manner that will allow informed decisions to be made about future land use within the Eola Hills. The study is intended to encourage effective landslide management and risk reduction strategies, and provide guidance for land use and construction.

PHYSIOGRAPHIC AND GEOLOGIC SETTING

The Eola Hills are located within the Willamette Valley geomorphic province, a broad lowland separating the Oregon Coast Range from the interior Cascade Range. The Willamette River flows north along the southern and eastern portions of the study area, separating the Eola Hills from the geologically similar Salem Hills to the south. The local topography ranges from flat alluvial plains along the Willamette River to moderately steep hummocky terrain and gentle and moderately sloping rolling hills in the uplands. Portions of the northern and southern margins of the hills consist of ancient landslide masses, exhibiting deranged drainage networks, local undrained depressions and sag ponds, and eroded headscarps. The Willamette River impinges upon the toe of the ancient landslide along the south side of the study area. The Eola Hills are cut by the deeply incised drainages of Gibson Gulch and Glenn Creek. The uplands are cut by broader, shallower tributary stream drainages.

Geologic mapping, detailed descriptions of the geologic units, stratigraphy, and structure are presented in Bela (1981), McDowell (1991), Burns and others (1992), Crenna and others (1994), and Wang and Leonard (1996). A typical stratigraphic section through the Eola Hills includes Eocene-Oligocene marine sedimentary bedrock overlain by basalt of the Miocene Columbia River Basalt Group (CRBG), and an upper mantle of residual, laterite soil. The sedimentary and volcanic bedrock is locally overlain by younger, unconsolidated to semiconsolidated alluvium and by thick residual soils that developed on the rock surfaces. The marine sedimentary units consist of sandstone, siltstone, and mudstone, with lesser amounts of conglomerate and interlayered localized volcanic rocks. The marine sediments are exposed in the northern part of the study area in the Gibson Gulch drainage along Brush College Road, where the strata dip 5° northwest (Bela, 1981). The sedimentary bedrock is overlain by Miocene volcanic rocks consisting of a thick sequence of basalt lava flows with interflow zones of flow-top breccia, ash, and baked soils.

Thickness of the basalt varies through the study area, ranging generally from 130 ft to 400 ft (Crenna and others, 1994). Individual lava flow thicknesses range from about 40 ft to more than 150 ft. The basalt sequence has a regional dip of about 2° to 4.5° northeast. The basalt surface is greatly modified by erosion and weathering and typically is mantled by a thick, red, clay-rich lateritic soil. The lateritic soil typically is about 5–20 ft thick, but local well logs suggest thicknesses up to 100 ft on the upland hills.

In the floodplains, valleys, and stream drainages, bedrock is overlain by varying thicknesses of Quaternary alluvium. The alluvial sediments include a "blue clay" unit and flood gravels of early Pleistocene age, fluvial sands and gravels of late Pleistocene age, terrace deposits of Pleistocene and Holocene age, and Holocene river alluvium (Wang and Leonard, 1996). Terrace sediments generally occur as equal elevation deposits around the margins of the Eola Hills. Prominent high-elevation terraces are present below an elevation of 250 ft, along the east and southeast sides of the Eola Hills. Low-elevation terraces are present in Spring Valley, north of the study area, and in areas between the east side of the Eola Hills and the Willamette River. Terrace deposits consist of unconsolidated to semiconsolidated gravel, sand, silt, clay, and organic deposits. Younger alluvium, consisting of unconsolidated cobbles, gravel, sand, and some silt and clay, occurs within floodplains and the active channel of the Willamette River as well as stream channels such as the lower reaches of Gibson Gulch and Glenn Creek.

Published geologic maps that include the study area have not identified faults within the Columbia River Basalt Group units in the Eola Hills. Faults within the bedrock units have been indicated in geologic studies of the Salem Hills to the south (Golder Associates, 1995), and it is reasonable to assume that concealed faults may be present in the bedrock of the Eola Hills. The top of the basalt at the eastern base of the Eola Hills may be offset downward by a fault, although existing data are insufficient to confirm a fault-controlled boundary (Crenna, and others, 1994).

Large areas of the northern and southern parts of the study area have been mapped as ancient landslide topography and associated colluvium and landslide debris deposits (Bela, 1981). The landslides are described as deep bedrock failures that occur within the marine sediments along the south and north flanks of the Eola Hills. Portions of the overlying basalts have been displaced with the downdropped and tilted fault blocks. The upslope boundary of the landslide topography is typically delineated by a moderately to steeply sloping escarpment, modified in most areas by erosion and stream channel incision. The most prominent identifying features of the ancient landslide terrain are hummocky topography, disrupted drainage patterns, sag ponds, springs, back-tilted bedrock blocks, and subdued headscarps.

DATA COLLECTION

The primary tasks accomplished to prepare the landslide hazard map included study of aerial photographs and limited field reconnaissance mapping, as well as review and compilation of various existing geologic, geotechnical, and hydrologic information. Evaluation of the degree of landslide hazard requires information on the geologic units (their distribution and characteristics), typical slope angles, surface water and groundwater hydrology, occurrence and type of existing slope failures, and man-made alterations to the land. The distribution of geologic units was determined from published geologic maps (Bela, 1981; Crenna and others, 1994; Wang and Leonard, 1996) and unpublished geotechnical reports. General slope angles were determined from the USGS 7½-minute topographic map of the study area, depicting 10-ft contour intervals. The actual slope of any specific site may vary somewhat from that shown on the USGS topographic map; therefore ground-surface slope angles for sites should be confirmed in the field prior to using this information for critical development and construction decisions.

Aerial photographs covering the study area were obtained from the U.S. Army Corps of Engineers. Color infrared (CIR) photographs included 1:30,000-scale images taken on September 11, 1979 and 1:24,000-scale true color images taken on December 17, 1996. Boundaries of landslide topography and indicators of slope movement (headscarps, debris flows, etc.) were mapped on the basis of detailed study of the stereo images, coupled with field reconnaissance mapping.

Regional and local groundwater hydrogeology was evaluated from selected water-well data obtained from the Oregon Water Resources Department (OWRD), published hydrologic reports, and unpublished hydrogeologic reports for planned subdivision developments. Rainfall data for the period of 1929 to 1998 were obtained from the Oregon Climate Service (affiliated with the College of Oceanic and Atmospheric Sciences, Oregon State University). The rainfall data were used to note annual rainfall trends, estimate recurrence intervals of high rainfall events, and generate simulated groundwater levels due to varying climatic conditions.

Limited field reconnaissance mapping conducted for this study confirmed geologic and geomorphic information from other sources and allowed observation of representative bedrock and soil exposures, and inspection of several recent slope-failure occurrences. Three days of field reconnaissance were performed in January and February 1999. Field work included driving the roads within the study area and noting indications of recent slope movement such as pavement breaks and distorted road surfaces. Recent subdivision developments were inspected to observe development density, grading practices, road locations, and slope and drainage conditions. The locations of landform features delineated from the aerial photograph study (such as ancient and recent landslides, debris flows, and scarps) were confirmed and modified during field reconnaissances. Delineation of the relative hazard areas was reviewed in the field, to group similar areas together.

LANDSLIDE HAZARDS

General

"Landslide" is a general term that describes a variety of natural processes involving the downslope movement of earth materials under gravitational forces. Landslide processes include sliding, falling, flowing, toppling, or spreading of earth or rock. Debris flows and torrents include abundant water, rock, soil, and organic debris. Movement rates for various types of landslides vary across an extremely wide range. Fast-moving landslides, including earthflows, debris flows, and rock falls, can cause severe property damage and loss of life. Slower landslides, such as translational slides and slumps may cause extensive property damage. Frequently observed landslide damage includes destruction of foundations and buildings, damage to roadways and utilities, and movement of materials onto downslope property, with associated loss of use of the properties involved.

Nationwide, landslide-related damages in the United States result in an annual cost to society of about $1.5 billion and account for an average estimated loss of 25 lives per year (AIPG, 1993). It is possible through geologic studies and mapping to anticipate where landslide hazards are the greatest. In particular, some key criteria for high landslide hazard include a prior history of landsliding in the same or similar geologic setting; low-strength, clay-rich soils; adversely oriented planes of weakness in soils or rocks; undercutting of slopes by natural or man-made events; and overloading of slopes, most commonly by man. Common factors in many landslide types are the hydrology and hydrogeology of a site. Seasonal or episodic reactivation of preexisting landslides is a common occurrence, where high precipitation is the trigger for reactivating an older landslide mass. In addition, changes in surface or subsurface water conditions may trigger landslide activity. By characterizing the types of landslide hazards that exist in an area, an evaluation can be made to select appropriate site development plans, construction methodologies, and surface or groundwater control. Using this type of evaluation, potential future losses can be dramatically reduced, as has been demonstrated in prior studies.

It has been demonstrated that ancient or preexisting landslide masses have a high potential for reactivation or renewed localized ground movements. In most older landslide masses, the forces tending toward instability are only marginally balanced against the forces maintaining stability. Many older landslides can be considered dormant due to a lack of measurable activity. Consequently, the presence of ground movement activity within older slide masses indicates that a high hazard exists. Landslides can be triggered by earthquake activity, high groundwater conditions or undermining of slopes due to stream erosion. In addition, human activities such as site grading, cuts and fills, vegetation removal, and changes in drainage and related groundwater conditions may aggravate natural conditions resulting in landslide events.

A review of landslide hazards in Oregon (Burns, 1998) indicates 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. In addition, steep slopes underlain with weak soils or rocks containing adverse discontinuities can result in local slides. The rock types within the Eola Hills include weak and low-permeability marine sediments overlain by dense basalt with prominent and pervasive discontinuities. This combination of rock types, along with clay-rich residual soils overlying the basalt, provides a setting that is susceptible to water-induced landsliding. Recent slope-movement processes identified in the study area include rock falls, debris flows, small-scale rotational slides, and movement of land areas within the ancient slide masses resulting in ground cracks, rock pop-outs, and toe bulges.

Method of analysis and discussion

The methodology used to delineate landslide susceptibility categories on the landslide hazard map takes into account the factors of geology (bedrock and soil types), existing landslides, slope angles, geomorphic landforms, and general surface water and groundwater hydrology. Geology and landform data were taken from published maps and geotechnical reports, supplemented with aerial photography analysis and reconnaissance-level field studies. Slope angles were taken from the USGS Salem West 7½-minute topographic quadrangle and are approximate. Existing landslides (ancient and recent) and other indicators of ground movement were identified as part of this study from aerial photographs, published maps, and data from geotechnical consultants and public agencies. Areas exhibiting landslide activity were field-checked during the reconnaissances. The approach of identifying existing landslide topography and field-checking for recent activity or critical geologic and hydrologic conditions allows a conservative delineation of water-induced landslide susceptibility areas for the regional map produced by this study.

INFLUENCES ON LANDSLIDE HAZARDS

Geology, soils, and topography

Geologic conditions that influence slope stability consist primarily of the slope geometry combined with the location of weak, adversely dipping rocks, such as units of the marine sediments. Within sloping portions of the study area, movement in these weak zones can be initiated by increased groundwater levels, increased load on the slope, removal of toe support, or other causes such as earthquake shaking. Weathered rocks exposed along steep escarpments are also susceptible to rockfalls due to natural erosional processes.

Soil conditions adversely influence slope stability when units are present that are susceptible to a loss of strength under saturated conditions. In addition, planar soil features such as contacts between different soil units create potential slip planes. The presence of deep, clay-rich soils overlying weathered basalt in the upland portions of the study area creates a potential ground movement hazard on moderate to steep slopes. Although these soils are normally stable under unsaturated conditions, the introduction of water by intense rainfall events, or changes in local drainage can initiate ground failure. Slopes of 15 percent and greater, where clay-rich soil overlies basalt bedrock, are particularly susceptible to movement when disturbed by development. Studies of the erosional problems related to land use activities (Meyers and others, 1979), have recognized that these slopes can also have extraordinary high rates of erosion when disturbed by road building and subdivision development.

Surface water and groundwater

Surface water

Surface water affects slope failure initiation and reactivation by processes of erosion and saturation of subsurface materials. Impoundments and wetlands encourage infiltration of surface water into soil and rock units. Surface water drainage characteristics vary throughout the Eola Hills depending mainly on the geology, topography, and land use development.

The upland parts of the study area (map Categories 1 and 4) are generally well drained, and characterized by surface water flow within shallow swales, depressions, and stream channels with very few areas of severe erosion or headcutting. Shallow channels occur mainly within the lateritic soil profile and are occasionally incised to the depth of the underlying weathered basalt. Larger drainages, such as Gibson Gulch and Glenn Creek (map Category 3), have deeply incised channels cut through the soil and into basalt bedrock and, in some areas, into the underlying marine sediments. Surface water flow in these creek channels has resulted in localized areas of slope failure caused by lateral erosion. Surface water drainages on the landslide mass along the north (map Category 2) side of the study area is generally within integrated, well developed stream systems, which carry runoff into the larger channels and to the Willamette River. Within the ancient landslide mass along the south side of the study area (map Category 5a), sag ponds, springs, seeps, and some poor internal drainages are found on the natural slopes. The stream system in this area is less well developed, and relatively inefficient in carrying surface water off the slopes. Steep slopes along the escarpments at the head of the ancient landslide (map Category 6) and along incised stream channels (map Category 3) are subject to concentrated runoff and debris-flow initiation.

Potential slope stability problems in the study area can be caused by land development practices that concentrate runoff, disrupt the natural drainage paths, or impound water and thus cause increased infiltration. The hummocky, poorly drained areas of the ancient landslide masses are particularly sensitive to changes that increase surface water infiltration. Although other parts of the study area have better drainage of surface water flows under the existing natural conditions, they also remain susceptible to erosion and water-induced ground movement caused by surface water concentration or impoundment.

Groundwater

The primary focus of the groundwater study component of the Eola Hills was to summarize from existing studies the general character of the regional aquifer and its potential effects on landslides in the study area. The study included review and evaluation of hydrogeologic and groundwater data, including selected well logs from the files of OWRD, and an assessment of the groundwater flow systems and the potential relationship to landslides. The City of Salem Aquifer Storage and Recovery System (ASR) project is located in the Salem Hills, across the Willamette River, south of the Eola Hills. The ASR will not affect groundwater levels in the Eola Hills.

Groundwater in the Eola Hills occurs at relatively shallow levels within the ancient landslide deposits, within the upper basalt layers and within deeper aquifers in the lower Columbia River basalts and the underlying marine sediments. Groundwater wells within the landslide masses along the north and south sides of the Eola Hills have static water levels ranging in depths from approximately 20 to 115 ft. Shallow perched water zones commonly occur in the upper layers of the basalts, at depths ranging from approximately 15 to 50 ft. Wells penetrating the deeper basalts and marine sedimentary units in the uplands area typically encounter groundwater at depths ranging from approximately 65 to 400 ft. Static water levels in wells completed in Columbia River basalt aquifers have fluctuated approximately 5 to 15 ft during a year in the low elevations of the Eola Hills, and up to 30 ft in the higher elevations of the hills (Price, 1967).

Because of lateral variations in the Columbia River basalt and assumed geologic structures (boundaries) in the area, substantial variations are apparent in the depth to the water table and the yield to wells. Faults within the basalt bedrock have been identified in the Salem Hills to the south, and it is reasonable to assume that the bedrock in the Eola Hills may be broken into semi-independent blocks by concealed faults. Bedrock fault blocks would likely affect groundwater flow and may serve as hydrologic barriers. The bedrock blocks likely are charged primarily from infiltration of local precipitation. Only within a few areas of the Eola Hills are enough water-level measurements available to reveal the possible effects of local geologic structures. Wells in the study area, which are noted in OWRD records as having been reconditioned, are generally deepened or abandoned because they go dry or produce insufficient water, not because of identified ground movement. Fluctuations in water levels in relatively shallow perched groundwater zones are likely a more important factor in the initiation of localized landslides than changes in groundwater levels in the deep aquifers.

Precipitation and climate

Average annual rainfall in the Salem area (as recorded at the Salem Airport) is approximately 40 in. per year over the 69-year period of record from 1929 to 1998 (Oregon Climate Service). Annual water-year (October to September) precipitation for the period of 1929 to 1998 is shown on Figure 2. Annual rainfall extremes of more than 10 percent over the average (44 to 61 in.) have occurred 20 times during the 69-year period of record.

Climate, specifically precipitation, is a key factor in slope stability issues. The most critical climatic triggers for landsliding in the Eola Hills include high-intensity rain storms of short duration, and extended seasonal rainfall periods with higher than average precipitation. Prior saturation of the ground by high antecedent rainfall and/or snowmelt during an intense extended precipitation event typically results in the highest number of ground failures. The resulting failures that occur during, or immediately following, these intense events include shallow soil slumps and debris flows. Most debris flows triggered by very high precipitation originate as shallow slumps or translational failures in the upper part of a drainage way. The failed mass bulks up and builds mass by incorporating water, saturated sediments, and debris from its stream channels.

Long periods of high precipitation increase the amount of groundwater infiltrating into shallow aquifers. Reactivation of historic or ancient landslide masses often occurs only in response to certain high groundwater conditions resulting from greater than normal water infiltration. Longer wet cycles, ranging from seasons to years, tend to reactivate larger, deeper seated, slow-moving landslides. Slide activity may be maintained while high-groundwater conditions exist and may continue under reduced groundwater levels due to loss of strength of the soils. Increased spring flows, seepage, and minor ground movement along the toe of the ancient landslide masses of the Eola Hills may be due to increased rainfall amounts during the 1996 to 1998 wet seasons. High groundwater levels in water wells in parts of the Eola Hills tend to peak within approximately 6 to 12 months of the

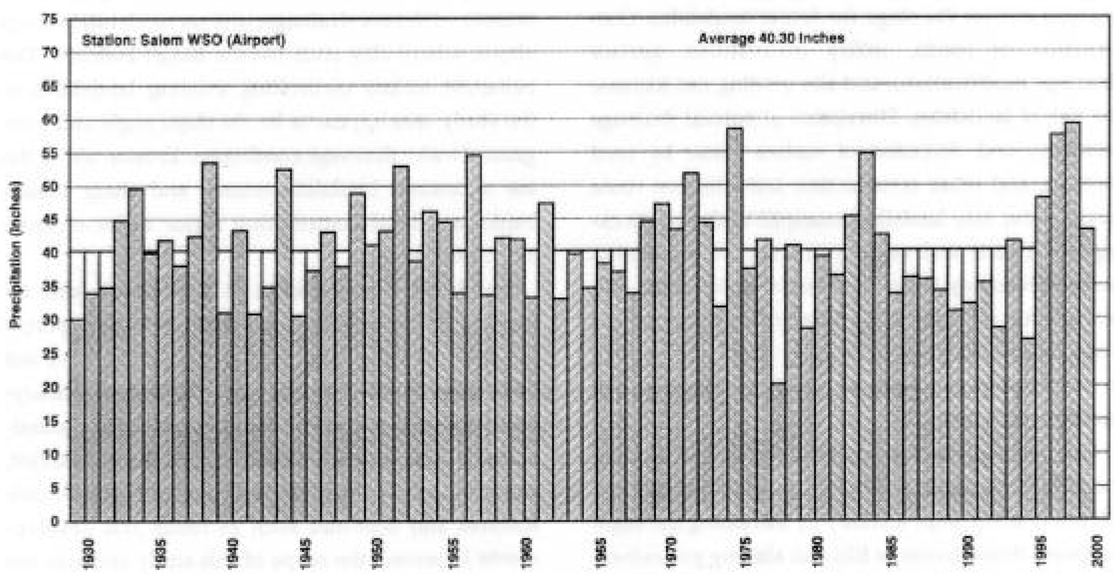

Figure 2. Annual precipitation — water year (October 1–September 30). Data from Oregon Climate Service.

extreme rainfall periods (OWRD well records). These high groundwater levels lag the rainfall events due to slow infiltration to deep aquifers, thus the deep groundwater levels typically do not influence slope stability.

Vegetation is also an important variable associated with climatic influences on slope stability. Vegetation influences the amount of precipitation reaching the ground surface, the rate of surface runoff, the amount of infiltration, and the long-term moisture conditions of the soil. Roots of vegetation add strength in the near-surface soil, but do not affect soil strength for deeper seated landslide movement. Removal of vegetation by logging or development can immediately increase localized runoff and soil erosion and decrease soil strength during the period of root decay, which may result in higher potential for shallow failure for a limited period of time following logging. In addition, removal of vegetation may increase infiltration of surface water.

Land use

Within the Eola Hills, a number of natural slopes (particularly those of 15 percent and greater) appear to be in a marginally stable condition and are considered landslide susceptible. In these areas, man-made changes can set the stage for future landslides. Construction of roads, utility excavations, surface drainage modifications, and site grading can increase the risk of landslides. Disruption of natural drainage pathways and diversion of surface water by road building and other construction activities can route storm water into landslide-susceptible slopes. Blocking of culverts and surface drainage is a common cause of roadway failure and landslide initiation. Recent ground movement in a subdivision development along lower Gibson Gulch is most likely due, in part, to soil saturation caused by roadway diversions of surface water flow.

Land development practices in the upland areas of the Eola Hills, on clay-rich soils overlying basalt can adversely affect slope stability by increasing the slope steepness through cuts or fills and altering groundwater conditions. Disruption of natural surface water drainages can result in changes in water infiltration and increase the hazard of an unstable slope condition.

MAP PRESENTATION

Susceptibility rating

The landslide hazard rating of the study area was divided into six landslide susceptibility categories, as presented on the landslide hazard map and explained in Table 1. The susceptibility categories represent the nature and relative degree of hazard for water-induced landslides and related slope failures in the study area. The categories are ranked, with Category 6 representing the greatest overall hazard, and Category 1 the least hazard, although the specific type of landslide hazard may vary between the areas. The categories were defined on the basis of the relative age and apparent degree of landslide activity as disclosed by topographic expression, the known historic ground instability, slope steepness, geologic setting, and slope drainage. Earthquake-induced hazards are not addressed.

Review of the hazard classification zones on the landslide hazard map indicates that there is a greater susceptibility for water-induced landslide activity where slopes are steep, in existing landslide masses with poor drainage, and on moderately steep slopes where clay soils overlie basalt bedrock. The principal factors controlling existing landslides in the study area appear to be the slope angle and poor groundwater drainage conditions. Erosion along the toe of ancient landslide masses and along stream banks is a local contributing factor in incremental slope movement.

Landslide characteristics at a particular site, including the specific type of landslide hazard, potential rates of movement, and area affected, have not been differentiated on the map. Geotechnical analysis of soil and rock material strength, local groundwater levels, bedrock structure and discontinuities, slope aspect, and the effects of particular man-made features and activities such as roads and developments is beyond the scope of this study and was not performed.

Table 1: *Rating categories of water-induced landslide susceptibility*

Category 6	High susceptibility to local landslides, debris flows, and rockfalls along steep escarpments, under adverse surface water and groundwater conditions.
Category 5a	High susceptibility to localized ground movement. Displays localized slope instability and poor drainage.
Category 4	High susceptibility to ground movement when disturbed by development. Includes slopes of 15 percent and greater where clay soils overlie basalt bedrock. General areas shown on map are sensitive to earthwork practices and to changes in surface and groundwater drainage and infiltration.
Category 3	Moderate susceptibility to debris flows, rockfalls, and localized landslides along steep drainage slopes.
Category 2	Generally low susceptibility to ground movement. Located within a dormant mature landslide mass with generally good drainage.
Category 1	Generally low susceptibility to landslides in upland areas on slopes less than 15 percent. An elevated risk of slope failure is not apparent.

Map categories and landslide hazard ratings

The landslide hazard map depicts by color those areas that represent one of the six categories of landslide susceptibility for water-induced slope movement. Each of the six categories has an associated landslide hazard rating. Although the categories are hierarchical, i.e., a higher number indicates a greater hazard, Categories 4, 5a, and 6 all have a hazard rating of "high," a significant degree of landslide hazard. This implies that all three zones have a high potential for damaging ground movement, either naturally or due to changes in site conditions resulting from development. Category 4 areas represent steeply sloping portions of the uplands outside of mapped landslides, where clay soils overlie basalt bedrock and slopes are generally over 15 percent. Categories 2 and 5a are both within the ancient landslide terrain along the north and south flanks of the Eola Hills. Category 5a is distinguished by the greater degree of massive landslide features (hummocky ground and disrupted drainage systems) and local areas of slope movement. Category 5a represents a potentially higher landslide hazard overall than Category 2, because of the typically poor drainage characteristics of land in Category 5a.

Recommendations for geotechnical investigations and risk reduction

The landslide hazard map also presents a matrix table associating the map categories with certain slope conditions, recommended levels of study, types of recommended geotechnical investigations, and landslide risk reduction options (Table 2). The column "Special geology and slope conditions" summarizes critical aspects of geology, soil, existing natural slope and drainage as well as the type and presence of identified ground movement. Recommended levels of geotechnical investigation are presented to guide planners and developers regarding the type of engineering geology and geotechnical engineering studies that will be necessary to fully identify and assess potential slope stability problems.

The matrix table also presents landslide risk reduction options, as generalized guidelines to land use and development practices, intended to limit slope and drainage disturbance. The purpose of the landslide risk reduction options is not to present a comprehensive list of practices or requirements, but to suggest methods to avoid creating adverse man-made conditions that may lead to unstable slopes.

This report and the accompanying landslide hazard map constitute the initial step in the delineation of areas susceptible to water-induced slope failures. The landslide susceptibility hazard map portrays relative slope failure hazard conditions in the map category areas. Locations considered for development should be further investigated at a "reconnaissance" level. A reconnaissance-level investigation typically includes a general characterization of geology, soils, hydrology, topography, and existing or potential geologic hazards in the proposed development location and the adjacent surrounding lands. A primary purpose of the reconnaissance-level investigation is to identify conditions and locations, which will need more and detailed engineering geology and geotechnical engineering evaluation. Reconnaissance-level studies are generally not detailed enough to evaluate hazards in a small area or individual site. In areas considered for development, the information presented in the reconnais-

Table 2. *Recommendations for geotechnical investigation level and risk reduction, by susceptibility category as shown on map*

Map category	Landslide hazard rating	Special geology and slope conditions	Level and type of geotechnical investigation recommended	Water-induced landslide risk-reduction options
6	High	Steep escarpments in bedrock and soil; known rockfalls, landslides, debris flows	*Level*: Detailed *Type*: Subdivision and site-specific engineering geology and geotechnical engineering reports	Restrict development and encourage use as undeveloped land and natural open space.
5a	High	Some active ground movement; most slopes over 15 percent; localized poor drainage conditions	*Level*: Detailed *Type*: Subdivision and site-specific engineering geology and geotechnical engineering reports	Restrictions on allowable development density; when building roads and structures, control surface water drainage; minimize earthwork; use of natural open space on critical slopes and drainage ways.
4	High	Clay soils overlying weathered basalt bedrock on slopes of 15 percent and greater; soil and weak rock sensitive to changes in slope, surface water, and groundwater conditions	*Level*: Detailed *Type*: Subdivision and site-specific engineering geology and geotechnical engineering reports	Restrictions on allowable development density; when building roads and structures, control surface water drainage; minimize earthwork; use of natural open space on critical slopes and drainage ways.
3	Moderate	Oversteepened slopes; stream erosion; potential debris flows and slope failures	*Level*: Detailed *Type*: Subdivision and site-specific engineering geology and geotechnical engineering reports	Restrictions on allowable development density and location; when building roads and structures, control surface water drainage.
2	Low	Some slopes over 15 percent; some debris flows and slope failures	*Level*: Reconnaissance *Type*: Subdivision engineering geology report; site-specific engineering geology and geotechnical engineering reports for slopes of 15 percent and greater	When building roads and structures, control surface water drainage; minimize earthwork; use of natural open space on critical slopes and drainage ways.
1	Low	Some slopes over 15 percent; extensive clay soils over weathered basalt bedrock	*Level*: Reconnaissance *Type*: Subdivision engineering geology report; site-specific engineering geology and geotechnical engineering reports for slopes of 15 percent and greater	Normal construction and grading standards on land with slopes less than 15 percent; special standards on slopes of 15 percent and greater to control drainage.

sance-level investigation needs to be augmented by more detailed engineering geology and geotechnical engineering investigations on subdivision or site-specific levels.

A "subdivision" study provides a more detailed and focused investigation of the potentially hazardous conditions within the area of a proposed development. A subdivision investigation is intended to characterize the geological and geotechnical conditions comprising the proposed development as a whole, and to express the geologic hazards, considering the existing conditions and the proposed changes in connection with site development. The subdivision-level report provides engineering geology and geotechnical engineering information necessary to avoid or mitigate potentially unsafe areas and hazardous conditions. The subdivision report should provide engineering geology and geotechnical engineering input on the surface and subsurface geologic conditions; identify the type and extent of geologic and geotechnical hazards; evaluate short-term and long-term land stability conditions; and assess the possible effects of the proposed land development on the subject property as well as on neighboring properties. The subdivision-level reports should also provide detailed information on potential problems that should be considered during the design phase of development features such constraints on location for lot layout, drainage, grading, roads, and utilities.

A "site-specific" report may be required for an individual lot or small area within a development where the previous subdivision-level report indicated an existing or potential hazardous condition. The site-specific report is intended to provide a detailed evaluation of geologic conditions, an assessment of the landslide hazards relative to the proposed development, and geotechnical design recommendations with specific attention to reduction of the landslide hazards. The site-specific report should provide detailed engineering geology and geotechnical engineering characterization needed to understand site constraints and mitigation plans for any identified hazards. Within the site-specific report, geotechnical design criteria are provided for foundation and retaining-wall design, drainage systems, site grading, and other construction activities.

INVESTIGATION TASKS AND RESPONSIBILITIES

Oregon law requires that engineering geologic and geotechnical engineering investigations be accomplished by qualified professionals properly licensed to practice in the State of Oregon. These investigations are commonly performed by both engineering geologists and geotechnical engineers. These two professionals play slightly different roles, as indicated by the following definitions adapted from a recent guide for using earthquake hazard maps (Spangle Associates, 1998).

Engineering Geologist: An engineering geologist studies earth materials and natural earth processes (e.g., earthquakes, landslides, sedimentation) and functions as an earth historian, who uses the geologic record as a basis to forecast future occurrences of geologic processes. An engineering geologist uses the knowledge of past and potential events to identify and characterize geotechnical problems that could affect the location, design, construction, and maintenance of structures and engineering works.

Geotechnical Engineer: A geotechnical engineer is a civil engineer who considers the effects of earth materials and geologic processes on structures and engineering works. Geotechnical engineers use information provided by engineering geologists in analyzing the effects of geologic conditions on proposed structures and in engineered designs to effectively address the geologic conditions. Thus, the geotechnical engineer accomplishes analyses and provides recommendations for geotechnical design, and completes an evaluation of the expected performance of the engineering work.

The engineering geologist and the geotechnical engineer often have overlapping and complementary responsibilities for the investigative tasks in a geologic hazards investigation. The geotechnical engineer ultimately provides specific design recommendations to implement the design, including mitigation plans for slope stability hazards.

MAP HAZARD CATEGORIES AND RISK REDUCTION STRATEGIES

The following sections discuss the nature and degree of water-induced landslide hazards in each map area, the potential impact of changing land use, and possible land use management strategies.

Category 6—Steep escarpments

The lands within Category 6 consist of steep escarpments along the headwalls of the ancient landslide masses and relatively steep slopes above Willamette River terraces. These occur as relatively narrow zones along the north, south, and southeast sides of the Eola Hills. Marine sedimentary rocks, Columbia River basalt, and residual soils are commonly exposed in the escarpment faces. Slopes in these areas commonly exceed 25° (47 percent) and, in some areas, exhibit local landslides, debris flows, and rock falls. Land within Category 6 is rated as highly susceptible to localized landslides, debris flows, and rockfalls under adverse surface water and groundwater conditions.

Relatively recent landslides and debris flows were identified within some Category 6 lands in aerial photographs and in the field. Debris flows and landslide scarps are particularly evident along the escarpment of the ancient landslide mass of the northern Eola Hills, where Walker Creek and Brush College Road drop down to Spring Valley. The debris flows and landslides appear to be currently stable. Slope failures are less evident along the escarpment of the ancient landslide of the southern Eola Hills, although slope movement evidence may be obscured by the dense vegetation. Recurring movement along portions of headscarps of the ancient landslide masses is evidenced locally by minor disruption of road pavements that cross this area. The steep erosional escarpment along the southeast Eola Hills in residential West Salem appears to be currently stable. No recent slope failures were observed during field investigations in this developed residential area. Naturally occurring geologic process such as erosion and weathering will occasionally result in unstable areas along these steep escarpments, and can be expected to produce localized landslides, rockfalls, or debris flows. The risk of naturally occurring slope failures can be expected to increase during and following intense or prolonged rainfall events.

Reduction of the risk of landslide initiation within Category 6 can best be achieved through constraints on land use, development, and drainage. Use of the undeveloped, steep land as natural open space will avoid potential slope instability problems resulting from development disturbances. Open space can also act as a buffer zone between the sites of future slope failures and developments on downslope lands. The slopes within Category 6 may be sensitive to changes in drainage from the lands upslope of the escarpment. Developments upslope of Category 6 lands need to consider the affect of changes in the surface and groundwater flows relative to slope stability along the escarpments. In this regard, appropriate setbacks from existing landslide scarps and surface water control plans are important in areas upslope and adjacent to Category 6 land. For areas within Category 6, detailed geotechnical investigations are recommended prior to any land development. Both subdivision and site-specific reports incorporating engineering geology and geotechnical engineering characterization should be prepared for areas proposed for development. These reports should describe the surface and subsurface geologic conditions, the existing natural hazards, the potential hazards that may result from developing the site, and geotechnical engineering design recommendations to assure stability in and adjacent to the development site area.

Category 5a—Ancient landslide mass

The lands identified as Category 5a lie along the south side of the study area and consist of an ancient large-scale landslide mass. Ancient movement of the landslide mass and subsequent geomorphic and erosional processes have resulted in hummocky topography, partially disrupted drainage networks, local undrained depressions and sag ponds, and eroded headscarps. Areas of localized active ground movement are apparently present near the headwall of the landslide mass, and along the landslide toe where the Willamette River or its flood plain impinges upon portions of the toe of the landslide.

Category 5a includes the southwest part of the study area, which lies between the escarpment and uplands of Categories 6 and 1 and the terraces and floodplain of the Willamette River and encompasses a portion of an ancient landslide mass that exhibits hummocky topography and some apparent landslide movement. Land within Category 5a is rated as highly susceptible to localized ground movement.

Overall, the Category 5a area has a moderately well developed stream network, and fairly good apparent groundwater drainage. Poor surface water drainage and apparently poor groundwater drainage occur along portions of the toe of the ancient landslide mass and in areas of small sag ponds downslope of the landslide headscarp. Surface water drainage typically enters shallow incised stream channels, which tend to terminate near the toe of the landslide mass. Along sag ponds and in the central part of the ancient landslide mass, the surface drainage ends in small ponds, depressions, and swales, resulting in persistent high groundwater in those areas. Springs, seeps, and saturated soils are seasonally to perennially present at the toe of the landslide mass, particularly within roadcuts and embankments along Highway 22 and the Southern Pacific Railroad.

The movement characteristics of the ancient landslide mass range from slow, creeplike movement to currently stable, with localized active ground movement in limited areas near the head of the landslide mass. Potentially active zones are expressed as ground bulges along the landslide toe and as small-scale slope failures occurring primarily on slopes of 15 percent and greater. Minor ground movement appears to be affecting roadways below the head scarp of the ancient landslide mass near the boundary with Category 6. Most flat to moderately sloping areas within Category 5a appear to have been relatively stable within the past few decades. In the absence of detailed site information, it is reasonable to assume that steep slopes (15 percent and greater) within the ancient landslide mass are potentially unstable under conditions of high groundwater and that large portions of the ancient slide mass could be reactivated along preexisting failure planes by persistent high groundwater conditions.

Category 5b, which was used in a similar study of the Salem Hills (Harvey and Peterson, 1998), is not applicable in the present study area.

Risk reduction and recommended site investigations

Reduction of the landslide risk within the ancient landslide mass of Category 5a includes both large-scale controls to reduce cumulative effects, and local controls on development density, land use, grading practices, and water drainage changes. The primary control in reducing the risk of new slope failures within the ancient landslide mass is to minimize water infiltration to the ground. Some methods to minimize infiltration include lining ponds, retaining through-flowing stream channels (not damming streams for ponds), and constructing roads and buildings to route surface water runoff to drainage ways. Retaining natural open space lands on steep slopes and critical drainage ways will avoid potential slope instability problems resulting from development disturbances. Open space along the head of the ancient landslide mass can also act as a buffer zone between future slope failure sites and downslope developments, serving to mitigate adverse changes in drainage in the uplands.

Within Category 5a, reconnaissance-level geotechnical investigations are recommended prior to any land development. Both subdivision and site-specific reports incorporating engineering geology and geotechnical engineering characterization should be prepared for any areas of planned development. These reports should identify ancient landslide features in the vicinity of the site and describe the surface and subsurface geologic conditions; identify the existing geologic hazards of the site and surrounding area; evaluate the potential hazards that might result from the proposed development; and provide geotechnical recommendations for the site development to minimize adverse onsite and offsite geologic impacts and assure control of water runoff and infiltration.

Category 4—Uplands of clay soil over basalt bedrock on slopes of 15 percent and greater

Category 4 includes critical portions of the uplands that are characterized by thick, clay-rich lateritic soils overlying weathered basalt bedrock on slopes of 15 percent and greater. Category 4 encompasses the steep portions of the hills and ridges, which exhibit the greatest sensitivity to changes in slope, surface water, and groundwater conditions. Land within Category 4 is rated as highly susceptible to ground movement when disturbed by development.

The Category 4 areas depicted on the landslide hazard map are slopes that have at least a 15-percent grade. The boundaries on the map were selected by measurement of slope gradients from the USGS topographic map (1:24,000 scale, 10-ft contour interval), and checked using GIS-derived slope maps. The actual slope gradient for specific sites may differ slightly from the slope determined from the topographic maps. Therefore, ground measurements at a site are required to confirm the actual slope gradients.

For initial land planning purposes, the Category 4 areas represent general locations that appear stable under existing slope and drainage conditions, but may have slope stability problems when disturbed. Conditions of slope instability can be initiated by increases in water infiltration to the soils and by site grading, i.e., cuts and fills. A slope failure occurred in 1997 on the lower part of a north-facing hillslope during development of the Gibson Gulch subdivision. The slope movement appears to have occurred after a cut was made into the base of the hillslope, and changes in drainage within the development routed surface water flow into the soil near the head of the cut. Two residences and a paved street were affected by the slope failure.

Risk reduction and recommended site investigations

For areas within Category 4, detailed geotechnical investigations are recommended prior to land development. Both subdivision and site-specific reports incorporating engineering geology and geotechnical engineering characterization should be prepared for planned developments. These reports should describe the surface and subsurface geologic conditions, the existing geologic hazards, the potential hazards that might result from developing the site, and provide design recommendations for site grading and water control to preserve and enhance existing site stability. Actual slope gradients, measured on the ground by approved surveying methods, are required to confirm the locations of slopes of 15 percent grade and greater.

Category 3—Oversteepened slopes along stream channels

Portions of the upper drainages of Gibson Gulch, Winslow Gulch, and Glenn Creek characterized by steep slopes resulting from stream erosion have been designated as Category 3. Category 3 encompasses the steepest lands along the drainages, which may be marginally stable and sensitive to changes in slope, surface water, and groundwater conditions. Land within Category 3 is rated as moderately susceptible to debris flows, rockfalls, and landslides.

Existing small-scale slope failures and debris flows were identified in aerial photographs and in the field. Slope failures on the steep side slopes of the drainages have occurred during the past few years in response to extreme rainfall events that resulted in ground saturation and increased surface runoff. No active slope failures were observed during field activities conducted in 1999. Minor ground movement (such as soil creep and isolated rock fall) most likely occurs periodically along portions of the steep side walls of the drainage. Low-lying land along the bottom of the channel valleys is subject to inundation and stream bank erosion during flood events. Although detailed site information was not collected throughout the drainages, it is prudent to assume that the steep canyon slopes are marginally stable based on the geologic setting and similarity to nearby active landslide areas. Naturally occurring geologic process such as stream erosion, debris flows, and rock weathering will occasionally result in unstable areas and can be expected to produce localized failures. The risk of naturally occurring slope failures, bank erosion, and flooding increases during and immediately after intense or prolonged rainfall events. Debris-flow initiation risk may be increased by changes in runoff, which will occur as development increases.

Risk reduction and recommended site investigations

Reduction of the risk of landslide initiation on the steep slopes within Category 3 lands can best be achieved through constraints on land use and by requiring appropriate facility siting, design, and construction practices. Use of the steepest portions of the land as natural open space will minimize future risk resulting from development disturbances. Development should be avoided in debris flow runout zones, which can be recognized through landform interpretation and the presence of debris-flow deposits. Open space can also act as a buffer zone between the sites of potential slope failures and developments along the valley bottoms. The slopes within Category 3 may be sensitive to changes in drainage from the lands upslope of the drainage (Category 1 and 4 lands). Developments upslope of Category 3 lands need to consider the effect of changes in the surface and groundwater flows relative to slope stability along the sides of stream channels.

For areas within Category 3, detailed engineering geology and geotechnical investigations are recommended prior to any land development. Both subdivision and site-specific reports incorporating engineering geology and geotechnical engineering characterization should be prepared for areas of planned development, including roadway construction. These reports should describe the surface and subsurface geologic conditions; identify existing geologic hazards;

describe the potential hazards that might result from developing the site; and provide recommendations as appropriate regarding facility siting, earthwork, foundation, and surface and groundwater control.

Category 2—Dormant mature landslide mass

An area along the north part of the study area, lying between the escarpment of Category 6 and Spring Valley has been identified as a dormant, mature landslide mass and presented as Category 2 on the map. Category 2 land encompasses the north portion of the ancient landslide mass along the side of the Eola Hills, which, in comparison with Category 5a, exhibits less hummocky topography, gentler slopes, more mature drainage networks, and lack of apparent recent, large-scale landslide activity. Land within Category 2 has a low hazard rating for susceptibility to ground movement.

Overall, the area has a well-developed stream network, and appears to have typically good groundwater drainage. Surface water drainage typically enters swales and incised stream channels, flowing northward to Walker Creek and Spring Valley and away from the toe of the ancient landslide mass. Springs and saturated soils are seasonally present along Walker Creek, north of the ancient landslide head escarpment.

The ancient landslide mass in the Category 2 area does not exhibit active large-scale ground movement. Historic debris flows and localized small-scale slope failures that were identified in aerial photographs and in the field appear to be currently stable. Periodically active ground movement most likely occurs in small areas adjacent to the ancient landslide headscarp. Most flat to moderately sloping areas within Category 2 appear to have been relatively stable within the past few decades. In the absence of detailed site information, it is assumed that steep slopes (15 percent and greater) within the ancient landslide mass are potentially unstable under conditions of increased groundwater and soil saturation. The risk of naturally occurring debris flows and localized slope movement can be expected to increase during and immediately after intense or prolonged rainfall events.

Risk reduction and recommended site investigations

Reduction of the risk of landslide initiation within the ancient landslide mass of Category 2 can best be achieved through controls on design and construction practices and through improving water drainage. The primary risk reduction measures within the ancient landslide mass include minimizing cuts and fills, careful site selection, and surface and groundwater control. Some methods to minimize groundwater infiltration include retaining through-flowing stream channels (not damming streams), and constructing roads and buildings to collect and route surface and groundwater to drainage ways. Road and building construction practices should minimize earthwork and control surface and groundwater drainage. Retaining natural open space lands on steep slopes (over 15 percent slope) and in critical drainage ways will avoid potential slope instability problems resulting from development disturbances. Open space along the base of the escarpment at the head of the ancient landslide can also act as a buffer zone between potential slope failure sites and downslope developments.

Within Category 2, reconnaissance-level geotechnical investigations are recommended prior to any land development. A subdivision report incorporating engineering geology and geotechnical engineering characterization should be prepared for any planned development area. A site-specific report incorporating engineering geology and geotechnical engineering characterization should be prepared for any areas of planned development on slopes expected to be 15 percent and greater, where debris flows and slope failures have previously occurred and in other higher risk areas identified in the reconnaissance level studies. Actual slope gradients, measured on the ground by approved surveying methods, are required to confirm the locations of slopes of 15 percent grade and greater. These reports should identify ancient landslide features in the vicinity of the site; describe existing geologic hazards and potential hazards that might result from the proposed development; and provide recommendations as appropriate, regarding earthwork, foundations, and water control.

Category 1—Uplands on clay soils

Category 1 land consists of upland areas that are characterized by rolling hills and valleys and generally underlain by thick, clay-rich lateritic soils overlying weathered basalt bedrock. The areas depicted on the map as Category 1 have slopes generally less than 15 percent grade, as estimated from slope angle measurements on the USGS topographic map (1:24,000 scale, 10-ft contour interval). However, localized steeper slopes may exist within the Category 1 area and require special attention during development. The actual slope gradient for specific sites within the boundaries of Category 1 on the map may differ slightly from the slope determined from the topographic maps. Therefore, ground measurements at a proposed development site are required to confirm the actual slopes. Within the Eola Hills, the Category 1 lands with slopes less than 15 percent generally exhibit the lowest relative sensitivity to changes in slope, surface water, and groundwater conditions. Land within Category 1 is rated to have generally low susceptibility to landslides on slopes of less than 15 percent.

Overall, the area has a well-developed stream network, and better apparent groundwater drainage than the ancient landslide masses bordering the Eola Hills. Surface water drainage typically enters shallow incised swales and stream channels, which flow to the major drainages of Gibson Gulch, Winslow Gulch, Glenn Creek, and other smaller streams. Springs and seeps are present near the head of some drainages and along the base of steeper ridges. These seeps and springs serve as discharge points for perched groundwater in the shallow aquifers.

The Category 1 uplands appear generally stable under undisturbed conditions. No slope failures were identified in aerial photographs or in the field reconnaissance. Flat to moderately sloping areas within Category 1 appear to have been relatively stable within the past few decades. However, minor areas of soil creep on slopes and soil erosion in drainage channels do most likely exist. Lands with slopes of less than 15 percent do not appear to have an elevated risk of slope failure under undisturbed conditions. The addition of water to the soil and a subsequent increase in groundwater saturation, may decrease slope stability. The risk of naturally occurring, localized slope movement may increase during and immediately after intense or prolonged rainfall events.

Risk reduction and recommended site investigations

Despite the low hazard that has been identified in Category 1, prevention of slope instability resulting from development relies on adherence to well-considered design, construction, and grading practices. The primary controls in reducing the risk of initiating slope movement within this area or adjacent higher hazard zones are to minimize cuts and fills and prevent excess water infiltration or concentrated runoff to sloping ground. Some methods to minimize infiltration include retaining through-flowing stream channels and constructing roads, utility trenches, and building sites to route surface water runoff away from slopes. Retaining natural open space lands on critical drainage ways and on steep slopes approaching 15 percent or greater will avoid potential slope instability problems resulting from development disturbances.

Within Category 1, reconnaissance-level geotechnical investigations are recommended prior to land development. A subdivision report incorporating engineering geology and geotechnical engineering characterization should be prepared for any planned development area. A site-specific report incorporating engineering geology and geotechnical engineering characterization should be prepared for any areas of planned development on slopes of 15 percent and greater. Actual slope gradients, measured on the ground by approved surveying methods, are required to confirm the locations of slopes of 15 percent grade and greater. These reports should describe the surface and subsurface geologic conditions; identify existing geologic hazards; describe the potential hazards that might result from developing the site; and provide recommendations, as appropriate, regarding earthwork and water control.

COMMENTS ON THE LANDSLIDE HAZARD MAP AND ITS USE

The map provided with this report conveys basic information regarding recognized water-induced landslide hazards in the Eola Hills area of Polk County. The map is intended to serve as a regional planning tool to help manage and guide future growth and offers a basis for making informed decisions concerning future development. The map, used in conjunction with other geologic hazard information and maps such as earthquake hazard susceptibility, may be used to help reduce the risk to property, critical facilities, and infrastructures through planning policy and other mitigation strategies. Implementation of risk management strategies will reside with local government agencies including the City of Salem and Polk County.

Presenting areas on the map as having higher landslide hazard susceptibility does not suggest that an entire area is unsafe. The map categories represent relative hazards and the potential of a hazardous slope condition. The map is not detailed enough to evaluate landslide hazards at an individual site. The actual risk in a specific area depends not only on the level of landslide susceptibility, but also on factors of land use, site drainage, engineering of structures, and other site-specific influences. Other hazards may pose additional risk factors, which may equal or exceed the risk of landslide occurrence at a specific site. Areas identified to be in higher landslide susceptibility categories can be specified for the incorporation of landslide risk reduction measures into the initial steps of land planning, decision making, and risk management.

It is possible that information contained on the map and in this report could be used inappropriately without careful consideration of the regional nature of the study and the inherent uncertainties. The map categories show relative risk of water-induced landslide hazards. They do not include information on the probability or potential extent of damage from landslides. **Information provided in this publication should NOT be used in place of subdivision or site-specific engineering geology studies. The relative hazard categories are not intended to replace site-specific or subdivision evaluations, such as for engineering analysis and design. Subdivision or site-specific landslide hazards should be addressed through investigations by qualified professionals properly licensed to practice engineering geology and geotechnical engineering in the State of Oregon. Other studies for the area, such as DOGAMI publication GMS-105 on earthquake-induced landslide hazards, should be consulted for additional natural geologic hazards information.**

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