

Water-Induced Landslide Hazards, Western Portion of the Salem Hills, Marion County, Oregon

1998

IMS-6
Water-Induced Landslide Hazards, Western Portion of the Salem Hills,
Marion County, Oregon

By A.F. Harvey and G.L. Peterson,
Squier Associates, Lake Oswego, Oregon

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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
5b	High susceptibility to localized and large-scale ground movement. Located within a massive landslide that exhibits local activity and very poor drainage.
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.

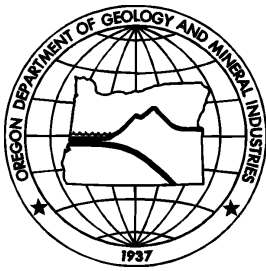
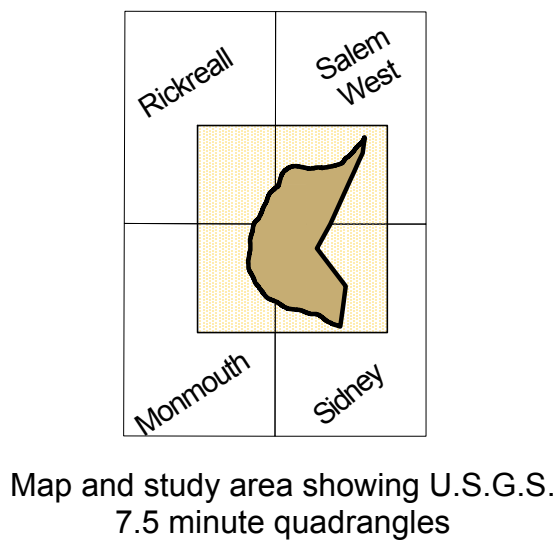
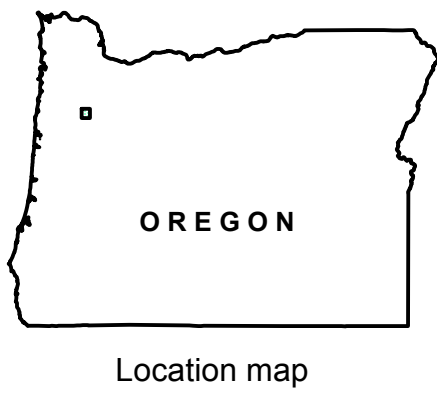
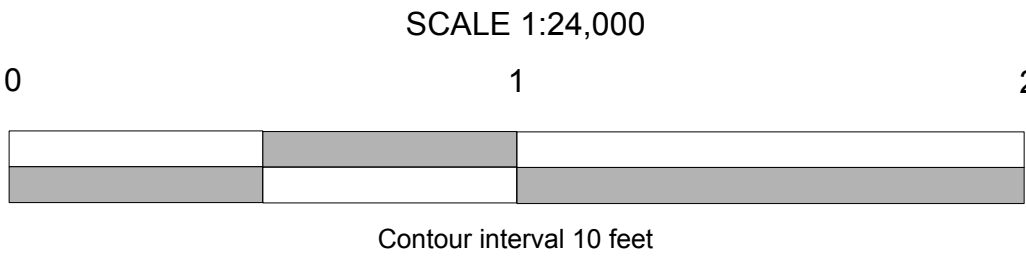
Recommendations for geotechnical investigation level and risk reduction, by susceptibility category as shown

Map category	Landslide hazard rating	Special geology and slope conditions	Level of geotechnical investigation	Water-induced landslide risk-reduction options
6	High	Steep escarpments in bedrock and soil; rockfalls; landslides; debris flows	Detailed; subdivision and site-specific engineering geologic reports	Use as undeveloped land and natural open space
5b	High	Active ground movement; most slopes over 15% grade; very poor drainage conditions	Detailed; subdivision and site-specific engineering geologic 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
5a	High	Some active ground movement; most slopes over 15% grade; localized poor drainage conditions	Detailed; subdivision and site-specific engineering geologic 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	Detailed; subdivision and site-specific engineering geologic 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	Detailed; subdivision and site-specific engineering geologic reports	Restrictions on allowable development density and location; when building roads and structures, control surface water drainage
2	Low	Some slopes over 15% grade; some debris flows and slope failures	Reconnaissance; subdivision engineering geologic report; site-specific engineering geologic report for slopes of 15% 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% grade; extensive clay soils over weathered basalt bedrock	Reconnaissance; subdivision engineering geologic report; site-specific engineering geologic report 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.

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

Base map derived from U.S. Geological Survey 7 1/2 minute quadrangles: Rickreall, Salem West, Monmouth, and Sidney, OR
The quadrangles were scanned and converted to vector files by the Engineering Support Unit of the Oregon Department of Corrections
Universal Transverse Mercator projection, zone 10
NAD 1927





Oregon

John A. Kitzhaber, M.D., Governor

Department of Geology & Mineral Industries

Administrative Office
800 NE Oregon Street #28, Suite 965
Portland OR 97232
(503) 731-4100
FAX (503) 731-4066

Interpretative Map Series IMS-6

Plan to reduce landslide losses in South Salem

A new project may help reduce landslide losses in Salem. Federal, state, and local governments are cooperating in a pilot project in the South Salem Hills, a landslide-prone area with intensive development.

The project began after the landslides in 1996 which damaged several houses. This area is important because the sliding is regional and can't be easily studied or controlled in tax-lot-sized parcels.

The Oregon Department of Geology and Mineral Industries (DOGAMI) coordinated the mapping and description of the South Salem Hills, producing a map that outlines six levels of risk. "This is a pilot project for us," explains Dennis Olmstead, the DOGAMI geologist who coordinated the project. "Most people don't know that landslides are the most expensive and dangerous geologic hazard. In the 1996 and 1997 storms, more people were killed in landslides than in floods. This project shows how federal, state, and local officials can work with the private sector to reduce future damage."

Oregon Emergency Management (OEM) received money from the Federal Emergency Management Agency (FEMA) for DOGAMI, the City of Salem, and Marion County to study the area and produce mitigation ordinances to reduce future losses. The consulting firm Squier Associates mapped the area.

The geology of the area is like many parts of the Willamette Valley: solid basalt over less stable, older marine sedimentary rocks. Water is a primary reason for slope failure, and the study took a comprehensive look at both surface- and groundwater.

In addition, the Geology Department will produce a landslide guidebook explaining landslide problems and possible mitigation techniques. This work is designed to help other communities that have similar problems. "One of the things a state agency can do well is transfer information between various jurisdictions," said John Beaulieu, DOGAMI's Deputy Director and author of the guidebook. "With some landslides, you can look at a specific building site and get all the information you need to protect the property. These large, regional landslides are more difficult to deal with. The process developed in Salem can be used in many other places." The guidebook is expected to be completed later this year.

Salem and Marion County will develop hillside ordinances for the study area and a model process that other communities with similar problems can follow. This is being done with public involvement at each level, and technical assistance from DOGAMI.

Water-Induced Landslide Hazards, Western Portion of the Salem Hills, Marion County, Oregon. DOGAMI Interpretive Map IMS-6, sells for \$10 and is available from the Nature of the Northwest Information Center, 800 NE Oregon Street #5, Portland, 97232, (503) 872-2750, www.naturenw.org; or DOGAMI field offices: 1831 First Street, Baker City, 97814, (541) 523-3133; and 5375 Monument Drive, Grants Pass, 97526, (541) 476-2496.

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STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
Suite 965, 800 NE Oregon St., #28
Portland, Oregon 97232

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NOTICE

The results and conclusions of this report are necessarily based on limited data and resources available for this project. Information provided in this publication should **NOT** be used in place of site-specific studies. For example, the susceptibility zones are not intended to replace site-specific evaluations, such as for engineering analysis and design. Site-specific landslide hazards should be assessed through geotechnical or engineering geology investigation by qualified practitioners.

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WATER-INDUCED LANDSLIDE HAZARDS, WESTERN PORTION OF THE SALEM HILLS, MARION COUNTY, OREGON

by Andrew F. Harvey and Gary L. Peterson, Squier Associates, Inc., 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 Salem Hills of Marion 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 west and south slopes of the Salem Hills, located between the Willamette River and the incorporated area of southwest Salem (Figure 1). Portions of the Salem West, Rickreall, Monmouth, and Sidney quadrangles are included

within the study area. The south and west slopes of the study area consist, in large part, of ancient landslide masses that exhibit recurrent, localized movement. The Salem 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 geotechnical investigations and risk reduction options for the various categories of landslide susceptibility. The

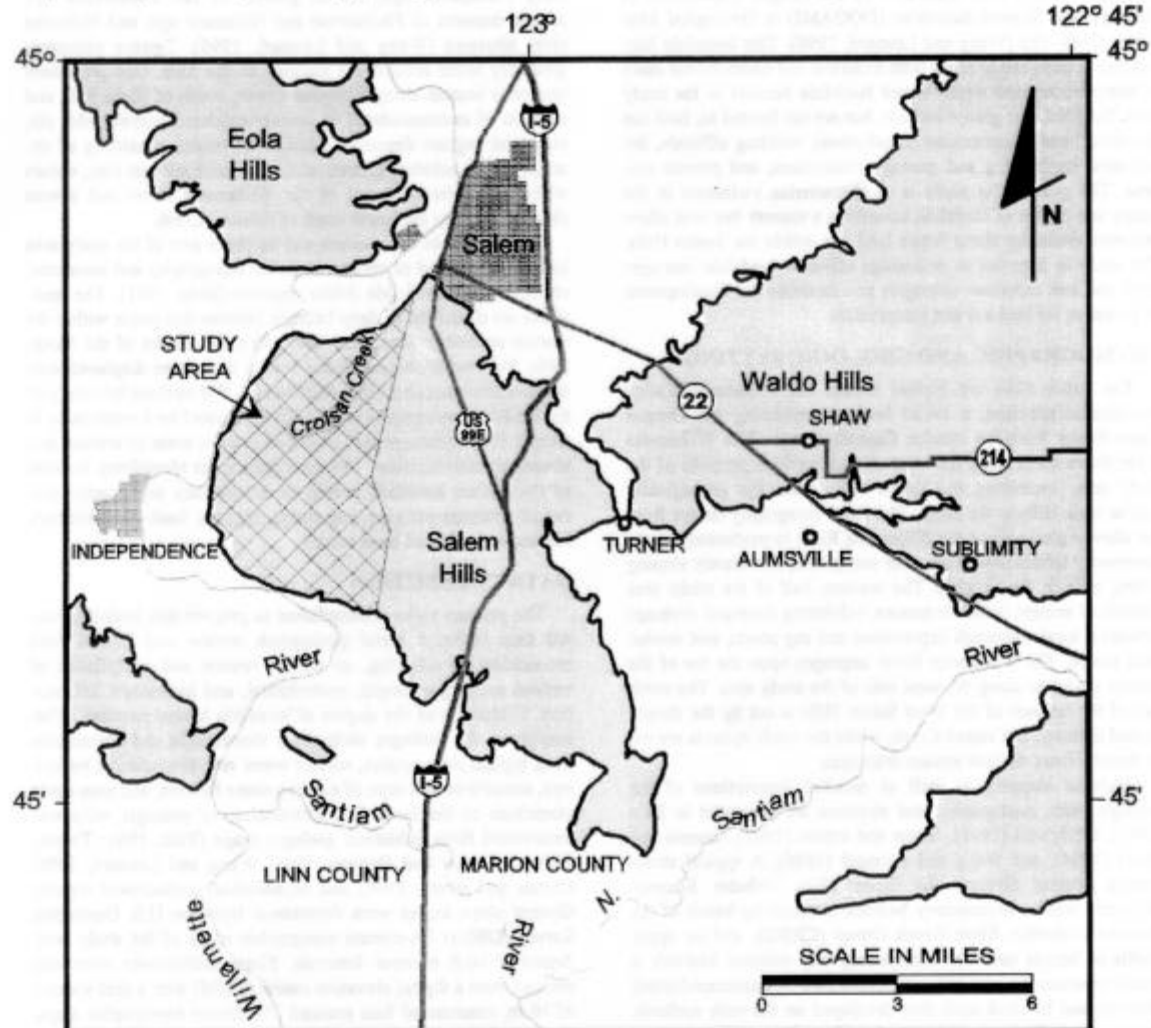


Figure 1. Sketch map showing location of study area (cross-hatched). Features shown are for illustrative purposes only and are approximate.

primary objective of the *Landslide Hazard Map* is to provide planners, developers, and the public with a tool that identifies the types of hazards 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. They have been addressed 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. Targeted user groups include, but are not limited to, land use planners, local governmental jurisdictions, building officials, developers, engineering and geology consultants, and private citizens. 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 about future land use within the Salem Hills. The study is intended to encourage effective landslide management and risk reduction strategies and facilitate the development of guidance for land use and construction.

PHYSIOGRAPHIC AND GEOLOGIC SETTING

The Salem 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 western and northern portions of the study area, separating the Salem Hills from the geologically similar Eola Hills to the north. The local topography ranges from flat alluvial plains along the Willamette River to moderately steep, hummocky terrain east of the river and gentle, moderately sloping rolling hills in the uplands. The western half of the study area consists of ancient landslide masses, exhibiting deranged drainage networks, local undrained depressions and sag ponds, and eroded head scarps. The Willamette River impinges upon the toe of the ancient landslide along the west side of the study area. The north part of the uplands of the West Salem Hills is cut by the deeply incised drainage of Croisan Creek, while the south uplands are cut by broader more shallow stream drainages.

Geologic mapping as well as 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 Salem Hills includes Eocene-Oligocene marine sedimentary bedrock overlain by basalt of the Miocene Columbia River Basalt Group (CRBG), and an upper mantle of laterite soil. The sedimentary and volcanic bedrock is locally overlain by younger, unconsolidated to semiconsolidated alluvium and by thick 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 southern part of the study area, where the strata dip 6°–12° north-northeast (Northwest Geological Services, 1994a,b). The sedimentary bedrock is overlain by Miocene volcanic rocks consisting of weathered and unweathered 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 400 to 600 ft. Individual lava-flow thicknesses range from about 40 ft to more than 150 ft. The basalt sequence has a regional dip of about 10° north-northeast. The basalt surface is greatly modified by erosion and weathering and typically is mantled by a thick, red, clay-rich lateritic soil. The red laterite soil is typically about 30 ft thick, but locally well logs suggest thicknesses up to 200 ft on the upland hills.

In the valleys and stream drainages, bedrock channels are overlain by varying thicknesses of Quaternary sediments. The alluvial sediments include a "blue clay" unit and flood gravels of early Pleistocene age, fluvial gravels of late Pleistocene age, terrace deposits of Pleistocene and Holocene age, and Holocene river alluvium (Wang and Leonard, 1996). Terrace sediments generally occur around the margins of the hills. One prominent terrace is located along Pettijohn Creek, south of Illahe Hill, and consists 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 the active channel of the Willamette River and stream channels such as the lower reach of Croisan Creek.

Large areas of the western and northern part 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 west and north flanks of the Salem 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 head scarps.

DATA COLLECTION

The primary tasks accomplished to prepare this landslide hazard map included aerial photograph review 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; Thayer, 1939; Schlicker and Deacon, 1968; Wang and Leonard, 1996; Crenna and others, 1994) and unpublished geotechnical reports. General slope angles were determined from the U.S. Geological Survey (USGS) 7½-minute topographic maps of the study area, depicting 10-ft contour intervals. Slope inclinations were also derived from a digital elevation model (DEM) with a grid spacing of 10 m, constructed from scanned 7½-minute topographic maps. The actual slope of any specific site may vary somewhat from that shown on the USGS topographic maps; therefore ground-surface

slope angles for sites should be determined 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 1:30,000-scale images taken on July 3, 1985. Black and white photographs included 1:48,000-scale images taken on April 6, 1986. Boundaries of landslide topography and indicators of slope movement (head scarps, debris flows, etc.) were mapped on the basis of detailed review of the stereo images, coupled with field reconnaissance mapping.

Information on recurrent ground movement and distress to public roads was obtained from the Marion County Public Works Department, Road Maintenance Division. This information included the approximate dates, locations, and amounts of ground movement that have affected River Road along the west side of the study area during the last 20 years. Little information is available regarding the recurrent crack patching that was obvious on numerous other roadways throughout the study area.

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. Additional information on the regional hydrogeology of the Salem Hills area was obtained from studies conducted for the Salem Department of Public Works regarding the planned Salem Aquifer Storage and Recovery (ASR) system, located in the Salem Heights area. The ASR reports included limited commentary and evaluation regarding the potential effects of groundwater injection and withdrawal on landsliding within the Salem Hills. Rainfall data for the period of 1930–1996 were obtained from the National Climatic Data Center. 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 May and June 1998. 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 location of landform features delineated from the aerial photograph study (such as ancient and recent landslides, debris flows, and scarps) were confirmed and modified during the 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 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 (American Institute of Professional Geologists, 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 reactivation of preexisting landslides is a common occurrence, where high precipitation is the trigger for activating landslides. 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 subsurface water 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 existing slide masses indicates that a high hazard exists. Landslides can be triggered by earthquake activity, high groundwater conditions due to high-intensity or prolonged rainfall, 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 Salem Hills include weak and low-permeability marine sediments overlain by high-strength basalts with prominent and pervasive discontinuities. These rock types, along with clay-rich residual soils overlying the basalts, provide a setting that is susceptible to water-induced landsliding where slopes are relatively steep and within existing slide masses. Recent slope-movement processes identified in the study area include rock falls, debris flows, mudflows, small-scale rotational slides, and movement of large land areas within the ancient slide masses that has produced 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 USGS 7½-minute topographic quadrangles 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 ground-movement 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 which influence slope stability consist primarily of the location of weakly cemented rocks, such as units of the marine sediments, and the presence of prominent or pervasive discontinuities in the basalt units. Within sloping portions of the study area, movement in these weak zones can be initiated by increases in groundwater, as well as other causes such as earthquake shaking. Weathered rocks exposed along steep escarpments are also susceptible to rockfalls due to natural erosional processes.

Soil conditions can influence slope stability when units are present that are susceptible to a loss of strength under saturated conditions. 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 Salem 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 little severe erosion or headcutting. The shallow channels occur mainly within the lateritic soil profile and are rarely incised to the depth of the underlying, more competent basalt. Larger drainages, such as Croisan Creek (map Category 3), Battle Creek, and Bates

Creek, have deeply incised channels cut through the soil and into basalt bedrock. 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 masses along the north (map Category 2) and south (map Category 5a) sides of the study area are 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 west side of the study area (map Category 5b), numerous sag ponds, springs, seeps, and poor internal drainages are found on the natural slopes. The stream system in this area is poorly developed, disrupted, and 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 Salem 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 (1) review and evaluation of hydrogeologic and groundwater data, including selected well logs from the files of OWRD; (2) review and evaluation of the proposed City of Salem Aquifer Storage and Recovery (ASR) System and its potential effect on landslides in the study area; and (3) an assessment of the groundwater flow systems and the potential relationship to landslides.

Groundwater in the Salem Hills occurs at relatively shallow levels within the ancient landslide deposits and within deeper aquifers in the Columbia River basalt and underlying marine sediments. Groundwater wells within the landslide masses along the west side of the Salem Hills have static water levels ranging in depths from approximately 40–100 ft. Wells penetrating the basalt and marine sedimentary units in the uplands area typically encounter groundwater at depths ranging from approximately 100–350 ft. The Columbia River basalt in the Salem Hills area is divided by faults into semi-independent blocks that get most of their groundwater recharge from infiltration of local precipitation. Because of lateral variations in the basalt and geologic structures (boundaries) in the area, substantial variations are present in the depth to the water table and the yield to wells.

Hydrogeology studies for the Salem Hills area (Montgomery Watson, 1995) identified faults along Croisan, Waln, and Battle Creeks and near Rosedale and Bunker Hill that likely affect ground water flow and may redirect ground water along other flowpaths. The faults along Croisan and Waln Creeks and the Mill Creek fault are situated in the vicinity of the proposed Aquifer Storage and Recovery System and may serve as hydrologic barriers with respect to groundwater flow in this area (Montgomery Watson, 1995). Only within a few areas of the Salem Hills enough water-level measurements are available to reveal the effects of

geologic structures. Wells in the study area that 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.

Effect of proposed Aquifer Storage and Recovery (ASR) system

The City of Salem ASR project has been investigated with initial field testing over the past few years. The ASR project's potential relationship to the Salem Hills landslide area has been addressed in studies conducted since 1994 (Montgomery Watson, 1994,a,b; 1995; 1996). The proposed ASR aquifer target zone is a weathered, vesicular, and fractured zone in the lower Columbia River basalt near the contact with underlying marine sediments. The ASR aquifer is located in a roughly circular depression centered about 3,500 ft west of Woodmansee Park, which places the estimated center of the aquifer about 4,000 ft east of the landslide study area's eastern boundary. The estimated aquifer radius is about 5,000 ft. The estimated west edge of the aquifer lies east of Croisan Creek, approximately 1,500 ft from the creek channel, close to the east edge of the landslide hazard study area. The aquifer generally occurs at depths from 285 to 330 ft below ground surface and has a maximum apparent thickness of 104 ft. The contact between the Columbia River basalt and the underlying marine sedimentary rocks is identified at an average elevation of about 100 ft within the ASR area. The basalt flows in the ASR area appear to have flowed into a shallow lake or marsh depression on the marine sediments, forming pillow basalts. The basalt units and the underlying marine sediments have a regional dip of about 6°–12° toward the north-northeast.

Natural groundwater flow in the ASR area occurs in a generally northerly direction toward the Willamette River. Groundwater levels in wells in the ASR area indicate a shallow groundwater zone ranging from 250 to 350 ft in elevation and a deeper zone within the lower ASR aquifer at approximately 190-ft elevation. Recharge to the ASR aquifer is through leakage from shallow groundwater. The ancient landslide mass along the west side of the Salem Hills ranges in elevation from approximately 200 to 800 ft. However, the ASR aquifer most likely pinches out to the west without reaching the ancient landslide area (Montgomery Watson, 1995; 1996).

Faults that might influence the hydrogeology of the ASR system include those along Croisan Creek, Rodgers Creek (Rosedale fault), Waln Creek, and Mill Creek. Down-to-the-east, near-vertical faults along Croisan Creek and Rodgers Creek may create barriers to horizontal groundwater flow, restricting westward movement of water injected into the proposed ASR. Currently, it is uncertain if the main basalt aquifer of the ASR system is displaced by these faults, since it may pinch out to the west short of these areas.

Feasibility studies for the ASR included injection of water into the basalt aquifer from wells installed in Woodmansee Park. Groundwater conditions near the northwest edge of the aquifer were primarily interpreted from data obtained from the Kreitzberg Well 4cb (Golder Associates, 1994a,b). The Kreitzberg Well 4cb is located east of the lower part of Croisan Creek, near the base of a steep, west-facing slope, approximately 8,500 ft northwest of the injection-well site. The well is screened at the approximate depth where the ASR basalt aquifer zone would occur, if it extended to this area. No apparent response in the water level was observed in the Kreitzberg Well 4cb during the injection test for ASR. The ASR groundwater study (Montgomery Watson, 1996) concluded

that the main ASR aquifer was not intercepted by the Kreitzberg Well 4cb and therefore not present at that location.

The ASR hydrogeologic studies (Montgomery Watson, 1996) concluded that it does not seem likely that water level changes due to ASR operations will affect the existing landslide terrain in the Salem Hills. Additional aquifer tests were planned by the City of Salem for the summers of 1998 and 1999 to inject, respectively, 3.5 and 7.5 million gallons of water into the ASR aquifer. Additional monitoring wells were to be completed within the landslide deposits south of River Road, west and east of Croisan Creek (Montgomery Watson, 1997). Water level monitoring in wells, springs, and streams was proposed, in an effort to determine whether the increased amounts of injected water may affect stability of slopes. As tests continue and additional data are obtained, potential impacts to slope stability in the Salem Hills study area should be reevaluated.

Precipitation and climate

Average annual rainfall in the Salem area (as recorded at the Salem Airport station) is approximately 40 in. per year over the 68-year period of record from 1929 to 1997 (Oregon State Climate Service). Annual precipitation amounts for the period of 1929 to 1997 are depicted on Figure 2. Annual rainfall extremes of more than 10 percent over the average (44 to 61 in.) have occurred 20 times during the 68-year period of record.

Climate, specifically precipitation, is a key factor in slope stability issues. The most critical climatic triggers for landsliding in the Salem 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 or snowmelt leading up to an intense precipitation event typically results in the highest number of ground failures. The resulting failures that occur during or immediately following these intense rainfall 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. This type of debris flow, accompanied by mudflows, occurred along the steep escarpment near the head of Fidler Creek during the heavy rainfalls of the winter of 1996–1997.

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 that result from greater than normal water infiltration. Longer wet cycles, ranging from seasons to years, tend to reactive larger, deeper seated, slow-moving landslides. Slide activity may be maintained as long as high groundwater conditions exist. Increased spring flows, seepage, and ground movement along the toe of the ancient landslide masses of the Salem Hills may be due to increased rainfall amounts of the 1996–1997 wet season. High groundwater levels in water wells in parts of the Salem Hills tend to peak within approximately 6–12 months of the extreme rainfall periods (OWRD well records). These high groundwater levels lag behind the rainfall events due to slow infiltration into deep aquifers.

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

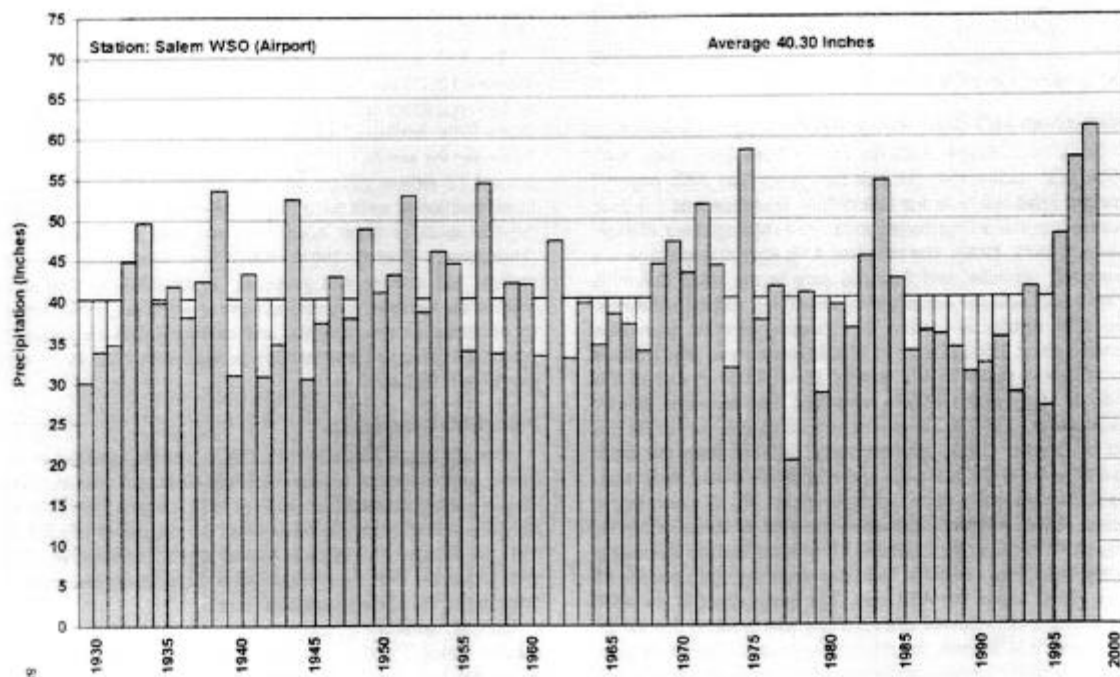


Figure 2. Annual precipitation since 1929 in the Salem area (water year is Oct. 1 to Sept. 30).

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.

Land use

It is assumed that a number of natural slopes within the Salem Hills (particularly those of 15 percent and greater) are in a marginally stable condition and are landslide susceptible. Man-made changes in soils, slopes, and drainages can set the stage for future landslides. Construction of roads, utility excavations, surface drainage modifications, and site grading can potentially 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 other surface drainage is a common cause of roadway failure and landslide initiation. Recent ground movement in subdivision developments along Croisan Ridge 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 Salem Hills, on clay-rich soils overlying basalt bedrock, have a great potential of reducing the natural stability of slopes. Slope stability in these areas can be reduced by increasing the slope steepness through cuts or fills and by reducing soil strength through increasing groundwater infiltration. Disruption of a natural surface water runoff channel 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 seven 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 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.

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 slide, rate of movement, and area affected, have not been differentiated on the map. Technical 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	Susceptibility rating and explanation
6	High susceptibility to local landslides, debris flows, and rock-falls along steep escarpments.
5b	High susceptibility to localized and large-scale ground movement. Located within a massive landslide that exhibits local activity and very poor drainage.
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.

Map categories and landslide hazard ratings

The landslide hazard map depicts by color areas representing one of the seven categories of landslide susceptibility for water-induced slope movement. Each of the seven categories has an associated landslide hazard rating. Although the categories are hierarchical, i.e., a higher number indicates a greater hazard, Categories 4, 5a, 5b, and 6 all have a hazard rating of "high," a significant degree of landslide hazard. This implies that all four 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 areas located within the uplands outside mapped landslides, where clay soils overlie basalt bedrock. In these areas, a high susceptibility to ground movement may result from site-grading changes and from sensitivity of this steep ground to adverse drainage changes. Categories 5a and 5b are both within the ancient landslide terrain along the west and south flanks of the Salem Hills. Category 5b is distinguished by the greater degree of massive landslide features (hummocky ground and disrupted drainage systems) and active slope movement. This category represents a potentially higher landslide hazard overall than Category 5a because of the typically very poor drainage characteristics of land in Category 5b.

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 geotechnical investigations, and landslide risk reduction options (Table 2). The column "Special geology/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 studies that will be necessary to fully identify and assess potential slope stability problems. For a specific site, the engineering geology and geotechnical investigations recommended should determine the type and extent

of geologic and geotechnical hazards, identify 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 recommended geotechnical investigations differentiate between reconnaissance-level and detailed engineering geologic studies. Reconnaissance-level studies are intended to produce a "subdivision" engineering geologic report that characterizes conditions for a proposed development as a whole, including such relevant issues as roadway design, utility alignments, storm-water drainage, lot layouts, and setbacks. Detailed studies are intended to produce site-specific engineering geology and geotechnical reports that include an evaluation of conditions at a specific site or lot and provide design recommendations that address the site issues. A site-specific engineering geologic report represents a comprehensive and detailed investigation that focuses on a specific proposed design. These detailed evaluations are recommended for areas within "high" landslide hazard ratings, i.e., Categories 4, 5a, 5b, and 6. Oregon law requires that engineering geology investigations and geotechnical engineering recommendations are to be provided by qualified professionals properly licensed to practice in the State of Oregon.

The matrix table also presents landslide risk reduction options as generalized guides 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, but to suggest methods to avoid creating adverse man-made conditions leading to an unstable slope.

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

Steep escarpments along the headwalls of the ancient landslide masses are generally included in Category 6. These occur as relatively narrow zones along the western and southern sides of the Salem Hills. Marine sedimentary rocks, overlying Columbia River basalt, and residual soils are commonly exposed in the escarpment faces. Slopes in these areas commonly exceed 25° (47 percent) and exhibit local landslides, debris flows, and rock falls. Land within Category 6 is rated as highly susceptible to localized landslides, debris flows, and rockfalls.

Recent landslides and debris flows were identified as belonging into Category 6 in aerial photographs and in the field. The movement characteristics of the recent slope failures range from actively moving to stable. Landslides incorporating red clay lateritic soil, weathered basalt, and portions of the underlying marine siltstone occurred in 1996 and 1997 along steep escarpments near Fidler Creek, in the northwest part of the study area. Slope failures within clay soils have occurred during the past few years in response to extreme rainfall events that resulted in ground saturation and high spring flows. Recurring movement along portions of head scarp of the ancient landslide mass is evidenced locally by disruption in the pavement of roads that cross this area. Naturally occurring geologic processes 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

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 of geotechnical investigation	Water-induced landslide risk-reduction options
6	High	Steep escarpments in bedrock and soil; rockfalls; landslides; debris flows	Detailed; subdivision and site-specific engineering geologic reports	Use as undeveloped land and natural open space
5b	High	Active ground movement; most slopes over 15% grade; very poor drainage conditions	Detailed; subdivision and site-specific engineering geologic 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
5a	High	Some active ground movement; most slopes over 15% grade; localized poor drainage conditions	Detailed; subdivision and site-specific engineering geologic 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	Detailed; subdivision and site-specific engineering geologic 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	Detailed; subdivision and site-specific engineering geologic reports	Restrictions on allowable development density and location; when building roads and structures, control surface water drainage
2	Low	Some slopes over 15% grade; some debris flows and slope failures	Reconnaissance; subdivision engineering geologic report; site-specific engineering geologic report for slopes of 15% 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% grade; extensive clay soils over weathered basalt bedrock	Reconnaissance; subdivision engineering geologic report; site-specific engineering geologic report 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

expected to increase during and following intense or prolonged rainfall events.

Reduction of the risk of landslide initiation within Category 6 areas can best be achieved through constraints on land use and development. Use of the 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 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-level and site-specific engineering geologic reports should be prepared or any areas proposed for development. These reports should describe the existing hazard, the potential hazards that may result from developing the site, and geotechnical design recommendations to assure stability in and adjacent to the development site area.

Categories 5a and 5b - Ancient landslide masses

The lands identified as Categories 5a and 5b lie along the west and south sides of the study area and consist of ancient large-scale landslide masses. Ancient movement of the landslide masses and subsequent geomorphic and erosional processes have resulted in hummocky topography, disrupted drainage networks, local

undrained depressions and sag ponds, and eroded head scarps. The landslide area within Category 5b has poor groundwater drainage conditions because of a poorly developed drainage network. The natural drainage network has been reestablished in areas assigned to Category 5a, where improved surface runoff results in a lower general landslide susceptibility. Areas of localized active ground movement are present near the headwall of the landslide masses and along the landslide toe where the Willamette River or its flood plain impinges upon portions of the toe of the landslide. A greater degree of apparent ground movement along the toe of the landslide mass is present within Category 5b areas, as compared with those in Category 5a. Recent ground movement along the head scarp of the slide mass is also more evident within Category 5b areas.

Category 5b

Category 5b land includes the landslide terrain bounded by the escarpment designated Category 6, between Illahe Hill on the north and Skyline Road on the south. Category 5b land encompasses the portion of the ancient landslide mass which exhibits the greatest degree of hummocky topography and poor, internal drainage. Land within Category 5b is rated as highly susceptible to localized and large-scale ground movement. These landslide mechanisms are predominantly due to local reactivation of portions of the ancient landslide mass. Some areas are seasonally active, causing ongoing disruption and damage to constructed works.

Overall, the Category 5b area has very poor surface water drainage and apparently poor groundwater drainage. Surface water drainage typically is impounded in small ponds, depressions, and

swales, which results in a high degree of infiltration. Springs, seeps, and saturated soils are seasonally present throughout much of the Category 5b zone, particularly at the toe of the landslide mass and within roadcuts and embankments along River Road.

Ground movement within the Category 5b area ranges from persistent to seasonally active to currently stable. Active ground movement occurs in both large and small portions of the ancient landslide mass and typically occurs as seasonal activity along well-defined failure zones. These are expressed as ground bulges along the toe of the landslide mass and as small-scale slope failures and narrow debris flows occurring primarily on slopes of 15 percent and greater. Along the area where the Willamette River impinges on the toe of the ancient slide mass, the ground movement has caused persistent deformation of the pavement of River Road and the grade of the Burlington Northern & Santa Fe Railroad. Minor persistent ground movement is also occurring along portions of the head scarp of the ancient landslide mass, as evidenced by disruption of pavement on roads that cross this area (for example, upper Vitae Springs Road). Areas that appear to have been relatively stable within the past few decades consist of the crests of hills and ridges and the relatively flat lands between these features. In the absence of detailed deformation data and site-specific information, it is reasonable to assume that much of the Category 5b area experiences small-magnitude, creeplike movements, which are difficult to observe without instrumentation or survey.

Recurrent or persistent, generally slow ground movements may occur throughout the Category 5b area. These movements could be initiated by climatic events or by site-specific or cumulative changes due to construction or groundwater. Because large areas could potentially be reactivated, special design approaches to assure satisfactory building performance may be required. In addition, special designs may be used for buried utilities and roadways.

Category 5a

Category 5a land includes the area southeast of the Category 5b area, lying between the uplands designated Category 1 and the floodplain of the Willamette River. The boundary between the Category 5a land and Category 5b land has been placed at the stream drainage along lower Skyline Road on the basis of the differing apparent degree of ancient landslide topographic development. Category 5a land encompasses the south portion of the ancient landslide mass which, in comparison with Category 5b, exhibits less hummocky topography, better integrated drainage networks, and less apparent ancient 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 better apparent groundwater drainage than the ancient landslide mass in Category 5b. Poor surface water drainage and apparently poor groundwater drainage occur along the toe of the ancient landslide mass and in areas of small sag ponds downslope from the landslide head scarp. Surface water drainage typically enters shallowly incised stream channels that tend to terminate near the toe of the landslide mass. Along sag ponds and at the landslide toe, the surface drainage ends in small ponds, depressions, and swales, which produces 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 River Road and the Burlington Northern & Santa Fe Railroad.

The movement characteristics of the existing ancient landslide mass range from slow creeplike movement to currently stable, with localized active ground movement occurring in limited areas of the ancient landslide mass. Active zones are expressed as ground bulges along the landslide toe near lower Skyline Road, and as small-scale slope failures occurring primarily on slopes of 15 percent and greater. Minor ground movement is affecting roadway crossings below the head scarp of the ancient landslide mass near the boundary with Category 5b land. 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.

Although less apparent than within the Category 5b area, the recent ground movement within Category 5a is also most likely initiated by recurring movement in blocks of soils and rock material initially disturbed by the ancient landslide. Poor drainage conditions throughout at least the landslide toe portion of the Category 5a area appear to be the primary factor of continuing slope instability. Localized slope movement and increased groundwater seepage indicated during the past few years appear to occur in response to high rainfall in recent years, which has raised groundwater levels. If such groundwater levels are maintained by continued high annual precipitation, deteriorating slope stability conditions could result.

Categories 5a and 5b—Risk reduction and recommended site investigations

Reduction of the landslide risk within the ancient landslide masses of Categories 5a and 5b 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 to the north and east.

Within both Category 5a and 5b, detailed engineering geology and geotechnical investigations are recommended prior to any land development. Both subdivision-level and site-specific engineering geologic reports should be prepared for any areas of planned development. These reports should describe the existing geologic hazards of the site and surrounding area and the potential hazards that might result from developing the site and provide geotechnical recommendations for the site development to minimize adverse 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 land 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. This 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 USGS topographic maps (1:24,000-scale, 10-foot 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 and cuts and fills.

For areas within Category 4, detailed geotechnical investigations are recommended prior to any land development. Both subdivision-level and site-specific engineering geologic reports should be prepared for any areas of planned development. These reports should describe the existing geologic hazards and the potential hazards that might result from developing the site and provide design recommendations for 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

The lower drainage of Croisan Creek, characterized by steep slopes resulting from erosion and stream development processes has been designated as Category 3. Category 3 encompasses the lands along the Croisan Creek canyon 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 drainage have occurred during the past few years in response to extreme rainfall events which resulted in ground saturation and increased surface runoff. No active slope failures were observed during field activities conducted in 1998. 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 valley is subject to inundation and stream bank erosion during flood events. Although detailed site information was not collected throughout the lower Croisan Creek drainage, it is prudent to assume that the steep canyon slopes are marginally stable, given the geologic setting and similarity to nearby active landslide areas. Naturally occurring geologic processes 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.

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. Avoidance of debris flow runoff zones can be accomplished through landform interpretation. Open space can also act as a buffer zone between the sites of potential slope failures and developments along the valley bottom of Croisan Creek. The slopes within Category 3 may be sensitive to changes in drainage from the lands upslope from the drainage (Category 1 and 4 lands). Developments upslope from Category 3 lands need to consider the affect of changes in the surface water and groundwater flows relative to slope stability along the sides of Croisan Creek.

For areas within Category 3, detailed engineering geology and geotechnical investigations are recommended prior to any land development. Both subdivision-level and site-specific engineering geologic reports should be prepared for any areas of planned development, including roadway construction. These reports should 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 water and groundwater control.

Category 2—Dormant mature landslide mass

An area northwest of Croisan Ridge, lying between the escarpment designated Category 6 and Pettijohn Creek and River Road 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 Salem Hills which, in comparison with Categories 5a and 5b, exhibits less hummocky topography, gentler slopes, more mature drainage networks, and apparent lack of 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 system and appears to have typically good groundwater drainage. Small, localized areas of persistent shallow groundwater occur along the base of the escarpment below Croisan Ridge, as indicated by small sag ponds near the ancient landslide head scarp. Surface water drainage typically enters swales and incised stream channels that flow northward to Pettijohn Creek and away from the toe of the ancient landslide mass. Springs and saturated soils are seasonally present at the head of Laurel Creek, north of Croisan Ridge. Sag ponds are present at the head of Laurel Creek and at the base of the escarpment west of Kuebler Road.

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 were identified in aerial photographs and in the field. Periodically active ground movement occurs in small areas adjacent to the scarp, as expressed by disruption of road pavement on lower Kuebler Road. Minor rockfalls occur along the toe of the ancient landslide north of the end of Croisan Ridge, where roadcuts have steepened the slopes. 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.

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 water 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 water and groundwater to drainage ways. Road and building construction practices need to minimize earthwork and control surface water and groundwater drainage. Retaining natural open space lands on steep slopes (over 15 percent slope) and critical drainage ways will avoid potential slope instability problems resulting from development disturbances. Open space along the base of the escarpment below Croisan Ridge 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 level engineering geologic report should be prepared for any planned development area. A site-specific engineering geologic report 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 describe existing geologic hazards; potential hazards that might result from developing the site; 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, as estimated from slope angle measurements on USGS topographic maps (1:24,000-scale, 10-foot contour interval). However, localized steeper slopes may exist within the Category 1 area and require special attention during developments. 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 measurement at a proposed development site are required to confirm the actual slopes. Within the Salem Hills, the Category 1 lands with slopes of 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 of the Salem Hills. Surface water drainage typically enters

shallow incised swales and stream channels that flow to the major drainages of Croisan Creek, Battle Creek, Wilkerson 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 the shallow aquifer.

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 is most likely occurring. Land 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.

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 are to minimize cuts and fills and prevent excess water infiltration on 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 steep slopes approaching 15 percent will avoid potential slope instability problems resulting from development disturbances.

Within Category 1, reconnaissance-level geotechnical investigations are recommended prior to any land development. A subdivision-level engineering geologic report should be prepared for any planned development area. Site-specific engineering geology and geotechnical reports should be prepared for any areas proposed for 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 and greater. These reports should describe existing geologic hazards and potential hazards that might result from site development and provide recommendations, as appropriate, regarding earthwork and water control.

COMMENTS ON LANDSLIDE HAZARD MAP AND ITS USE

The map provided with this report conveys basic information regarding recognized geologic hazards in the Salem Hills area of Marion 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 studies 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 Marion County.

Presenting areas on the map as having higher landslide hazard susceptibility does not suggest that an entire area is unsafe. The actual risk in a specific area depends not only on the level of landslide susceptibility, but also on factors of land use, engineer-

ing of structures, and other site-specific influences. Other hazards may pose additional risk factors that 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-level 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. Subdivision-level or site-specific landslide hazards should be addressed through engineering geology investigations by qualified professionals properly licensed to practice 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 hazards information.

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