

Cascadia

News and information from the Oregon
Department of Geology & Mineral Industries

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Fall 2006

Technology dramatically improves hazard mitigation mapping

Seeing landslides with LIDAR

Much of Oregon is susceptible to landslides, particularly portions of the state with moderate to steep slopes and a wet climate. As population growth continues to expand and as development into steeper terrain occurs, landslides pose significant threats to people and infrastructure.

By locating vulnerable areas precisely, we limit the scope of hazard identification to only those areas that are truly at risk. It is difficult to identify where landslides have occurred or where landslides or debris flows may occur using conventional aerial photography and remote sensing. Even detailed geologic mapping and field reconnaissance are liable to miss many landslide prone areas if the areas are masked by thick vegetation.

LIDAR (Light Detection and Ranging) data give us much better images of surface geomorphology, allowing identification of features associated with landslides.

Inside this issue of CASCADIA, you'll learn about LIDAR and how this technology helps DOGAMI scientists map slides and debris flows.



Are you standing on a landslide? In this 2005 high-resolution aerial photo (top) of the Gladstone, Oregon area, trees, houses, and roadways hide the contours of a large landslide. On the basis of this image, there is little geohazard risk in the area. In a "bare earth" image derived from LIDAR data for the same area (bottom) the surface is created by digitally removing all vegetation and man-made structures, resulting in a true surface shape accurate to 6 inches true height vertically. The water tank foundations are still visible but, in addition, landslide scarps and toes in the middle of image are clearly visible. This kind of resolution is not possible with other existing technologies. With LIDAR data we will be able to focus efforts on areas of high risk, saving resources, infrastructure, and lives. LIDAR surveys will dramatically affect our ability to identify areas of Oregon at risk.

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Phase 1 of proposed LIDAR mapping project would cover western third of Oregon

By Don Lewis, DOGAMI Assistant Director, Geologic Survey and Services Program

LIDAR is an inexpensive, fast, and better way to obtain superior details of the true shape of the earth's surface, as compared with existing decades-old topographic maps and the digital elevation models (DEMs) derived from them. We use LIDAR DEMs as an accurate and precise base for detailed geologic mapping and to radically improve our landslide, earthquake, coastal change, and tsunami inundation hazard assessment maps.

Current efforts in identifying hazardous areas are, by default, "blurry," as the underlying topographic resolution itself is poor. Existing topographic maps were interpreted manually from aerial photos taken decades ago. They are obsolete and there are myriad errors, especially in forested areas like western Oregon where the map makers could not see through the forest canopy. As a result, slopes are smoothed out and stream gradient detail is absent. This existing topographic base

(continued on page 3)



Notes from your State Geologist

—All about landslides

by Vicki S. McConnell
Oregon State Geologist

What goes up must come down... Every mountain, hillside, and slope is eroding away due to the forces of gravity helped along by wind and water and geologic processes such as earthquakes and volcanoes. So why does this natural and continual geologic process deserve such interest and scrutiny from our Agency, from legislators, from emergency responders, insurance companies, developers, cities and counties, and you and me?

Unfortunately, landslides do not always occur slowly and steadily over time. "Landslide" is catch-all term covering a wide variety of earth movement processes from slow creep occurring over years or decades to debris flows and lahars that travel up to 100 km (60 mph) an hour. Areas that have high rainfall or periods of intense rainfall, certain susceptible rocks and soils, slopes that have been denuded of vegetation, and areas on or at the foot of slopes that are subject to development may experience increased landslide hazards. We have included in this publication a handy "Landslides in Oregon Fact Sheet" on pages 9-10.

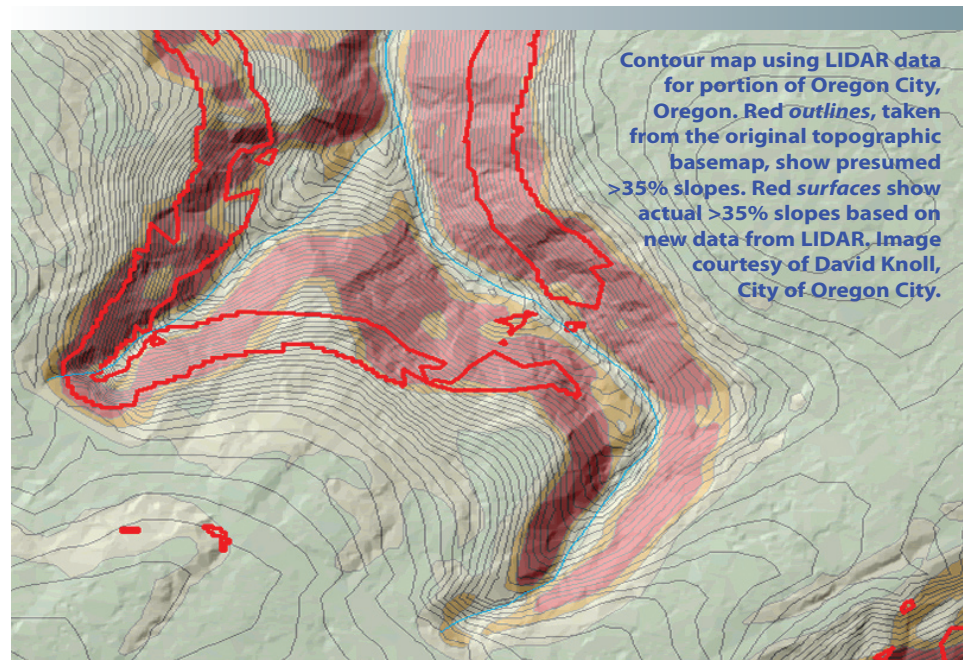
Oregon and Washington have abundant landslide-prone areas, from coastal bluffs to eastern mountain ranges. Landslide activity is in the news nearly every year in western Oregon and, during high rainfall winters, can result in loss of life and considerable damage. Nationwide landslide activity causes damage costing up to \$3.5 billion a year and causes between 25 and 50 deaths. In Oregon the winter of 1996-1997 was marked by several severe Pacific Northwest storms that initiated widespread slope failure throughout the state. Five deaths were associated with debris flow activity and estimates of damage during one storm alone

were \$280 million. Turn to page 8 to learn about how the state responded to this catastrophe as summarized during the 2006 Landslide Forum: A Decade Later. The unusually wet January of this year resulted in a Governor's disaster proclamation for flooding and landslides in 13 counties.

It is in the Department of Geology and Mineral Industries's mission to characterize and provide mitigation strategies for all geologic hazards, landslides included. We have for several years addressed landslide and debris flow hazard characterization on a project-by-project basis. We focused on identification of "further review areas" for rapidly moving landslides as requested by the Oregon legislature in 1999 (SB 12). Our initial strategy for SB12 was to be more inclusive when setting hazards areas for all of western Oregon. The resulting product has not been useful for local governments and land use planners developing land use policies. We have been more

successful with our landslide mapping in coastal areas where we are working on evaluating coastal hazards and erosion.

Within the last year some exciting changes have occurred that bode well for our work on landslide hazards. We have begun to acquire LIDAR data and images. LIDAR technology produces very accurate topographic information allowing landslide and debris flow hazard areas around the state to be more precisely located, as shown in the figure below. See pages 4-5 of this *Cascadia* for a brief explanation of LIDAR. We also have initiated a cooperative Landslide Hazard Program with the U.S. Geological Survey and are coordinating project goals with our federal colleagues. In the short term we are working on detailed landslide hazard evaluations in the Portland metropolitan area, completing the 5-year monitoring study of the Johnson Creek Landslide on Highway 101, preparing for a 2-day landslide hazard workshop in the Spring 2007. Longer term, we are focused on comprehensive risk assessments of landslide and debris flow hazards and are working with the USGS and other state agencies to design a landslide early warning system for highest risk areas. Ultimately, all our data and publications will be available through our geoscience website.



Proposed statewide LIDAR mapping

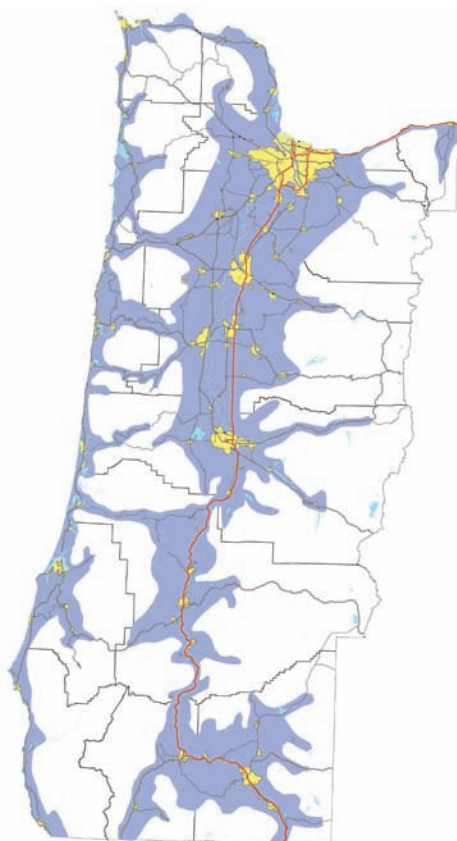
(continued from page 1)

is frequently incomplete, artificial, and simply wrong. High-quality hazard assessment maps cannot be generated from poor quality topographic data.

With accurate, precise, and high resolution DEMs, such as those based on LIDAR data, we achieve superb hazard assessment. When combined with wise planning, we sharpen the focus on truly dangerous locations for landslides, floods, coastal erosion, tsunami inundation, and seismic activity. Focused effort saves resources, money, and opportunity on both the front end during planning and on the back end for recovery.

The largest LIDAR data collection projects in the United States., in North Carolina and Minnesota, were spurred on following catastrophic damage caused by flooding from Hurricane Floyd (1999, \$4.5 billion) and the 1997 Red River flood (1997, \$1.5 billion). The North Carolina legislature allocated \$23 million for statewide LIDAR data collection in 2000 toward flood map modernization, and FEMA has contributed another \$6 million. Other states initiating large scale LIDAR projects include Louisiana, Iowa, Pennsylvania, Maryland, Wyoming, Wisconsin, Washington, California, and Hawaii. To their credit, several Oregon counties and cities have conducted small footprint LIDAR surveys (less than 60 square miles); however, such studies usually do not benefit from economies of scale possible with large-scale projects. Current LIDAR survey rates range from \$850/mi² for 50 mi² areas to \$430/mi² for 250 mi² areas.

Although it was considered the second worst flood along the Red River (after 1826), the 1997 flood was simply a larger version of floods that occurred in 1950, 1966, and 1979. Similarly, major floods along the Willamette River reoccur on about a 20-year cycle. "100-year events" occur with a 20-year frequency. The 1996-97 rain-mudslide-flood events took six lives and caused \$731 million in damage.

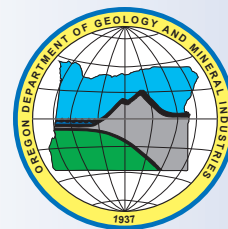


Extent of proposed initial LIDAR survey (in blue) in western Oregon. Areas were selected on the basis of population density, urban growth boundaries (yellow), transportation corridors, land use, and flood, forest fire, and landslide prone areas in proximity to population centers.

This past 2005-06 winter season heavy rains pounded northern California and Oregon, resulting in disaster declarations for floods and landslides in both states. Collecting and analyzing LIDAR data will facilitate Oregon being prepared for the inevitable natural disasters in our future.

Every Oregon agency, county, city, and private sector enterprise that uses, impacts, or depends upon the configuration and details of the surface of Oregon will benefit from access to high-quality LIDAR data. Nationally, LIDAR is considered to have a 1.5:1 benefit-cost ratio for flood map modernization purposes alone.

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PRINTED ON RECYCLED PAPER

Unprecedented detail from remote sensing data

Understanding LIDAR

By Don Lewis, DOGAMI

Most people are familiar with radar (Radio Detection and Ranging). Radar is a system that uses radio waves to detect, determine the direction and distance and/or speed of objects such as aircraft, ships, terrain, or rain, and map them.

LIDAR (Light Detection and Ranging) is similar to RADAR but uses rapid pulses of light energy particles (photons) instead of radio waves. During the past decade LIDAR has revolutionized mapping.

A LIDAR survey system collects tremendous quantities of three-dimensional point data where photons have been reflected off opaque objects like buildings, trees, bushes, and the ground surface. The dense amounts of spatial data provide surprisingly high-resolution, three-dimensional models of the shape of, and of what is on, the surface of the earth. LIDAR-based, three-dimensional models and images are thus far superior to the traditional maps we are familiar with.

Currently, LIDAR data are correct within a few inches of their true absolute elevation in space and to within a few feet laterally. In addition to being better data, LIDAR data collection is far faster than by other survey techniques and is inexpensive, averaging \$500 per square mile for larger survey areas.

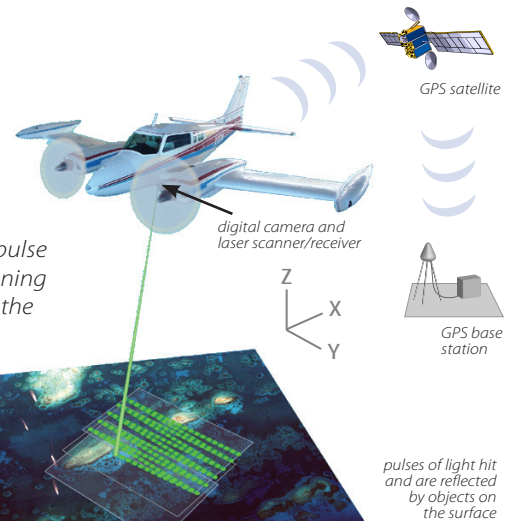
DOGAMI uses bare earth DEMs to identify existing natural hazards like earthquake faults and landslides that normally are very difficult to detect in forested terrain, as well as to construct accurate, precise, and high-resolution hazard maps and risk assessments.

The images on the facing page illustrate some advantages of LIDAR data, as compared with other data types for the Tryon Creek State Park in southwestern Portland. This LIDAR survey was flown for our agency using funds provided by the National Earthquake Hazards Reduction Program. The aerial photograph and DEM images were generated by the City of Portland Bureau of Planning.

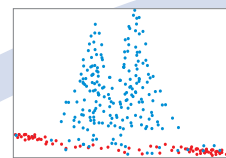
Collecting the data

A LIDAR system consists of a scanning pulse laser scanner and receiver, a Global Positioning System (GPS), including base stations on the ground within the survey area, and an Inertial Navigation System that records the exact orientation of the scanner.

The laser emits up to 150,000 pulses of light per second. Light energy reflection return times off the surface are measured. Reflections off tall or high objects have faster return times than those reflecting off the ground surface. This important feature allows us to compare what is on the surface, such as trees or buildings, with where the true surface of the bare earth is.



pulses of light hit and are reflected by objects on the surface



Resulting "data cloud" of all data collected. Here, blue indicates all returned data reflections while red indicates "bare earth" data, or the last-returned reflections.

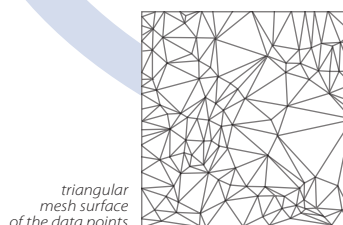
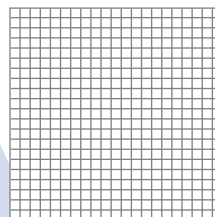
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531047.900	178946.030	521.690
531002.070	178975.660	525.700
531038.280	178922.590	527.100
531037.470	178923.490	520.100
531035.490	178924.130	520.370
531034.420	178925.330	528.230
531074.600	178912.830	520.100
531093.410	178943.010	520.400
531094.720	178943.490	521.350
531091.810	178947.240	522.460
531092.780	178945.960	520.700
531052.440	178900.370	520.650

Processing the data

LIDAR data are recorded as a cloud of X, Y, Z points. Computer processing creates a triangular mesh surface of the points that is turned into a regularly sized surface grid. The grid data set is known as a digital elevation model (DEM). A DEM can be built of everything that is on the surface or only the points that represent the last reflections from the surface.

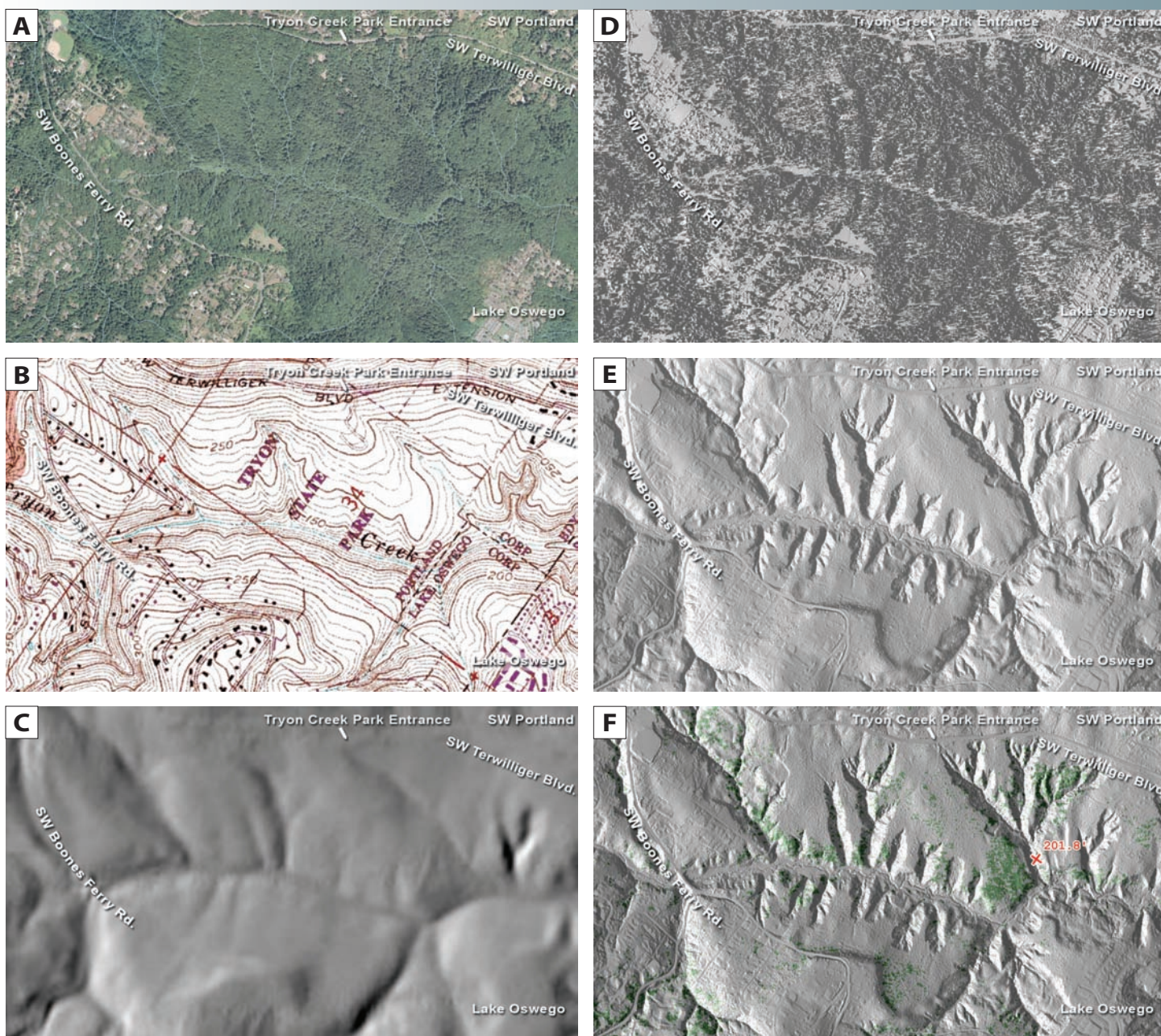
Displaying the data

From the mesh a digital elevation model is created. Hill shading and coloring are applied to create the final map. A 10-m DEM from LIDAR data of the West Linn, Oregon, Highway 205 area is shown here.



triangular mesh surface of the data points





Tryon Creek State Park, Portland, Oregon. Advantages of LIDAR data over other data types.

- (A)** Aerial photograph (area is 8,000 feet across) used to build contour maps. A map maker cannot see details of what is under the tree canopy, including actual locations of creeks and stream gradient detail.
- (B)** 1961 USGS 1:24,000 scale topographic map of the area. The contours reflect the general trend of the surface. A few features, such as buildings in the lower right, were added from 1981 photography. These dates are typical for all topographic maps across the country and are thus decades out of date. Major features like interstate highways can be missing.
- (C)** Digital version of the topographic map. The contours used to construct a DEM are considered "good" to within 10 meters (33 feet). The resulting image is fuzzy. Creeks can be missing, detail is absent, and the information can be just wrong, such as when streams appear to connect when they do not. In the past, this

was the best kind of topographic data available to create hazard assessment maps. Because the data are fuzzy, assessments can be crude and overly conservative, thereby placing the hazard in the wrong location, placing the hazard over too large an area, or missing the hazard altogether.

- (D)** LIDAR DEM of everything on the surface when the survey was flown in 2004. Individual trees can be mapped.
- (E)** LIDAR bare earth DEM that is a "virtual deforestation" of the area. The software program has also removed man-made objects such as buildings and bridges. The intimate detail of the earth surface is revealed. Compare with (C).
- (F)** The same LIDAR bare earth DEM, but this time with the location and distribution of all trees over 100 feet tall (green shading). This is a simplistic version of how LIDAR is being used for forest inventory measurement. The tallest tree in Tryon Creek State Park was located in this 2004 survey and was 201.8 feet tall. (Images A, D, E, and F courtesy of Kevin Martin, City of Portland.)

Pilot study

Mapping Portland landslides with LIDAR

By Ian Madin and Bill Burns, DOGAMI

In 2005, DOGAMI began a 5-year cooperative landslide research program in Oregon with the Oregon Department of Forestry, Portland State University, and the U.S. Geological Survey (USGS). These efforts will help to understand landslide processes and identify areas at risk from landslides so that landowners and local governments can take steps to mitigate the hazards and protect Oregon residents. While our partners are trying to answer fundamental questions about where, how, and why life-threatening debris flows develop, DOGAMI has focused on developing accurate and complete maps of existing landslides in inhabited areas of the state.

The first year of the DOGAMI portion of the program, funded in part by a USGS cooperative agreement and in part by DOGAMI, consisted of several tasks:

- Convene a landslide forum to commemorate the 1996-97 landslide events and to spread awareness of hazards to local government officials (see page 8).
- Conduct a pilot study in the Portland Hills examining the relative cost and efficacy of landslide mapping techniques, include new LIDAR imagery.
- Develop deep-seated landslide susceptibility maps of the pilot study area based on the mapped landslides.
- Test the use of LIDAR topography with DOGAMI's existing model for debris flow hazards.

These projects are nearing completion. The initial results led DOGAMI to develop two main tasks for the second year:

- Develop a statewide digital map and database of all landslides depicted on existing geology and hazard maps.
- Systematically map existing landslide using LIDAR in the Portland metropolitan area, using new LIDAR slated for acquisition in the winter of 2006-2007.

In addition, we are beginning to work with local governments to develop appropriate engineering, land use, and regulatory responses to the new landslide maps.

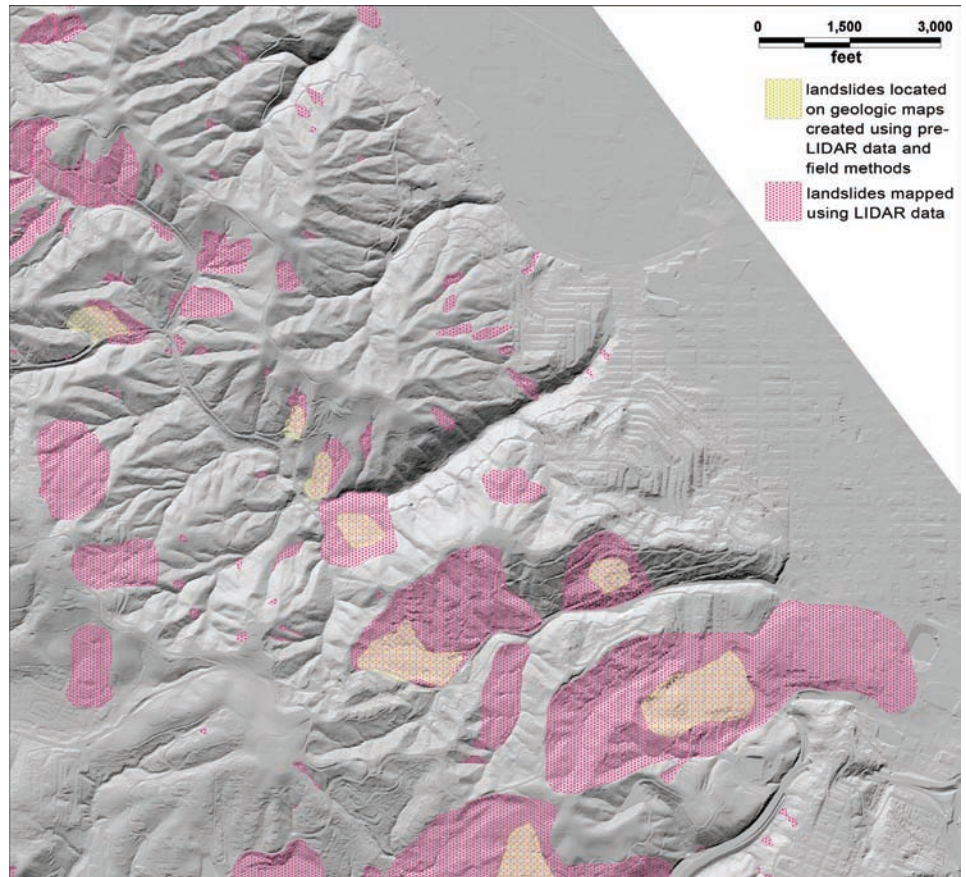


Figure 1. Landslides in Portland Hills, Oregon area. Highway 26 is in the southeast corner of the image. Slides from the 1990 geologic map of the Portland quadrangle are mapped in yellow-green hatch, slides identified largely by LIDAR in the pilot study are in magenta hatch.

Clearly, the most important result of the DOGAMI program has been that in heavily-vegetated urban areas, LIDAR is the essential tool for mapping existing landslides. Meaningful mitigation activities require a complete and accurate map of where the hazard is, and the key to making that map is to know where existing slides are.

In our pilot study in the Portland Hills, we compared the efficacy of landslide mapping using existing topographic data (USGS 10-m digital elevation models (DEMs) and City of Portland 5-ft photogrammetric contours), with mapping by air photos (serial stereo pairs spanning 1936 to 2000) and DEMs based on bare earth LIDAR data acquired over the last

few years. Using LIDAR (Table 1) data was far and away the most effective and efficient method, not only in finding the largest number of slides, but also in ease of identifying landslides and the precision with which their boundaries could be mapped. Where existing geologic maps showed only a handful of larger slides, the LIDAR-based map shows dozens, including many smaller slides (Figure 1).

Another great advantage of LIDAR mapping for landslides is that it is possible to map subtle signs of past debris flows. These landslides are typically fairly small, but because they move rapidly, they pose a serious threat to life and safety. Determining which slopes and channels are subject to these flows is difficult, but with LIDAR

Portland landslide mapping

(continued from page 6)

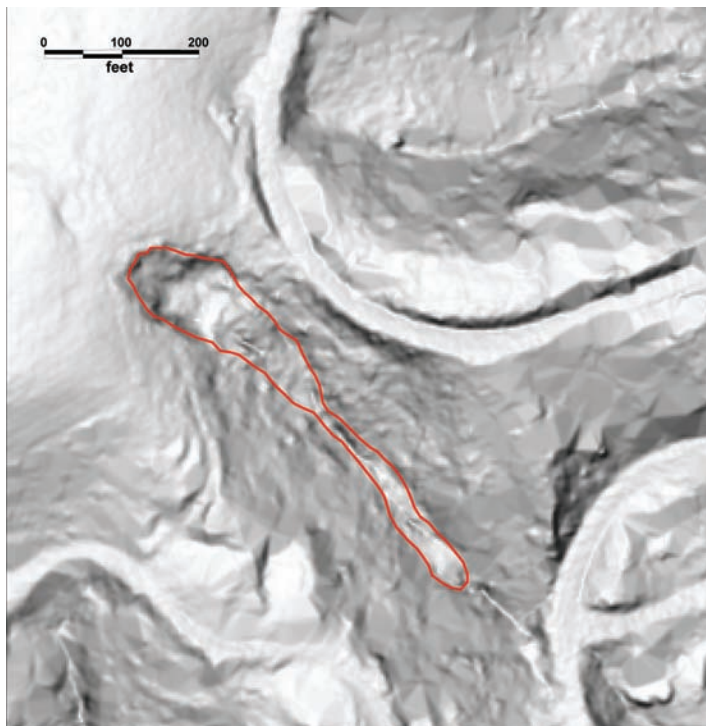


Figure 2. Small debris flow visible in map made from LIDAR data. Red line traces the shallow scars at the head of the steep stream channel and the debris flow deposits in the channel.

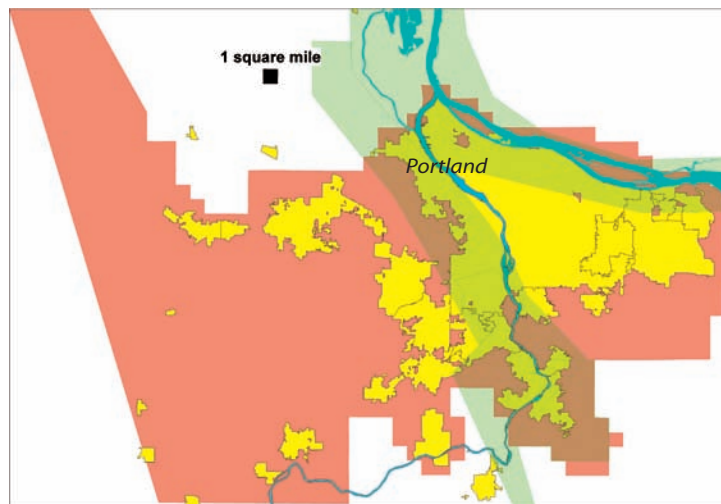


Figure 3. LIDAR imagery planned for the Portland urban area. Salmon zone is area proposed for LIDAR data acquisition in winter 2006-2007, green zones show areas with existing data, yellow areas indicate metro area cities.

Table 1. Comparison of effectiveness and efficiency of Portland Hills landslide mapping based on different data sets. LIDAR data enabled mappers not only to locate more landslides in less time but to find many smaller slides that were not found with other data sets based on other technologies.

	Data Set			
	USGS 10-m DEM*	City of Portland Data	Stereo-Pair Aerial Photograph (1973)	LIDAR
All four data sets mapped by one geologist				
Smallest landslide found (meters ²)	106,988	5,330	2,019	80
Largest landslide found (meters ²)	7,208,710	7,216,927	6,048,897	5,993,277
Landslides found hours spent average landslides found per hour	11 6 1.8	34 10 3.4	31 21 1.5	211 37 5.7
Each data set mapped by a different geologist				
Smallest landslide found (meters ²)	34,693	1,694	8,111	28
Largest landslide found (meters ²)	309,185	3,050,746	959,016	92,640
Landslides found hours spent average landslides found per hour	6 8 0.8	69 11 6.3	18 10 1.8	151 39 3.9
Average (all mappers)				
Landslides found hours spent landslides found per hour	8.5 7 1.2	51.5 10.5 4.9	24.5 15.5 1.6	181 38 4.8

*DEM is digital elevation model.

data it is possible to see the shallow scars at the heads of stream channels and debris deposits in channels that result from past flows (Figure 2). Mapping these deposits will allow us to determine which areas are at risk from future debris flows.

DOGAMI is currently working with the USGS and METRO (Portland Metro Regional Government) to try to complete LIDAR data acquisition for the entire metro area. The current plan is to acquire data (Figure 3) in the winter of 2006-2007, and then begin to map all existing landslides in the area of LIDAR coverage starting in the summer of 2007.

With our new-found ability to accurately map most of the existing landslides in a given area, we will be able to produce hazard maps that are based more on observed facts on the ground than on models. These new maps will give local governments the key to focused and appropriate mitigation measures.

Proposed statewide LIDAR mapping *(continued from page 3)*

The overall net benefit is far higher, given the multi-application utility of LIDAR in Oregon.

In addition to geologic hazards assessment, LIDAR DEMs are used for:

- forest inventory and forest life cycle management practice assessment
- floodplain map modernization
- urban planning
- emergency management
- coastal change mapping
- dam safety and sediment movement
- stream structure and fish passage
- riparian and wetland mapping and restoration design
- wildfire fuel load assessment
- road corridor and transmission line design
- hydraulic and hydrologic analyses
- archeological investigations
- outdoor recreation planning

DOGAMI is best positioned to administer a state-wide program of LIDAR data acquisition, maintenance, and dissemination, as it is the agency's mission to build natural resources and hazards spatial data sets that benefit the citizens of Oregon. DOGAMI integrates detailed mapping, resource and hazard assessment, and data distribution to industry, the public, and state, county, and city agencies; a LIDAR data collection program is the next step.

In our LIDAR program we will:

- build a coalition of stakeholders
- recommend LIDAR survey areas based on:
 - where Oregonians live
 - infrastructure and lifeline corridors
 - hazards where they impact life safety and property

The LIDAR survey will:

- cover 10,000 square miles (one third of western Oregon)
- benefit from large economies of scale; the estimated cost is only \$4.5 million
- result in DEMs being available to all Oregon and federal agencies, counties and cities; private consultants, industry, the public-at-large, and to non-profit organizations. The data will be public domain.

10 years later: Landslide forum recalls devastating 1996 flood and landslide events

On February 6, 2006, The Oregon Department of Geology and Mineral Industries hosted a landslide forum in Salem, Oregon to mark the 10th anniversary of what has been characterized as 100-year events for landslides in Oregon.

The main objective for the forum was to review the events of 1996 and Oregon's response to the landslide hazard. DOGAMI and guest presenters updated more than 150 participants on state and local government activities to understand and mitigate the hazard and shared insights on how to improve our response capability. The forum targeted a broad spectrum of attendees from federal and state agencies, local government and the general public.

Presenters included speakers from the USGS, Governor's Office, Department of Forestry, Oregon Emergency Management, National Weather Service, Department of Land Conservation and Development, Department of Geology and others.

Keynote lunch speakers included Scott Burns, Portland State University, and a presentation of the outstanding mitigation efforts in the State of Oregon for 2005, including Distinguished Leader in Natural Hazard Risk Reduction to Senator

Peter Courtney.

Participants were reminded that the fatalities and losses resulting from the 1996 landslide events brought about, among other things, the Governor's Debris Avalanche Action Plan and passage of Oregon Senate Bill 12, which authorized the mapping of areas subject to rapidly moving landslides and the development of model landslide (steep slope) ordinances.

The forum reviewed progress made in the characterization, understanding, and forecasting of landslide events, as well as how Oregon's debris flow warning system works and what state and local government can do to increase public awareness of landslides issues.

One final goal of the landslide forum was to remind all Oregonians that landslides will continue to occur. Educating policy makers and the public about the wide nature and complexity of landslides and land use issues will help everyone make informed decisions and create cost-effective policies that will reduce risk and save lives.

Forum PowerPoint presentations can be viewed at <http://www.oregongeology.com/sub/Landslide/forum2006/index.htm>



2006 landslide forum speakers answer questions from participants.

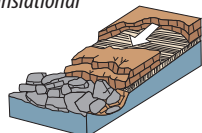
Common landslide types and triggers

COMMON LANDSLIDE TYPES

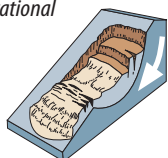
TRIGGERS AND CONDITIONS

SLIDES — downslope movement of soil or rock on a surface of rupture (failure plane or shear-zone). Commonly occurs along an existing plane of weakness or between upper, relatively weak and lower, stronger soil and/or rock. The main modes of slides are translational and rotational.

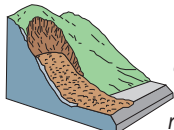
translational



rotational



FLOWS — mixtures of water, soil, rock, and/or debris that have become a slurry and commonly move rapidly downslope. The main modes of flows are unchanneled and channelized. Avalanches and lahars are flows.



unchanneled flows—
left: earth flow;
right: debris avalanche



channelized flow

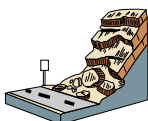
SPREADS — extension and subsidence of commonly cohesive materials overlying liquefied layers.



TOPPLES / FALLS — rapid, nearly vertical, movements of masses of materials such as rocks or boulders. Toppling failures are distinguished by forward rotation about some pivotal point below or low in the mass.



topple



fall

Slides are commonly triggered by heavy rain, rapid snow melt, earthquakes, grading/removing material from bottom of slope or adding loads to the top of the slope, or concentrating water onto a slope (for example, from agriculture/landscape irrigation, roof downspouts, or broken water/sewer lines).

Slides generally occur on moderate to steep slopes, especially in weak soil and rock.

Flows are commonly triggered by intense rainfall, rapid snow melt, or concentrated water on steep slopes. Earth flows are the most common type of unchanneled flow. Avalanches are rapid flows of debris down very steep slopes.

A channelized flow commonly starts on a steep slope as a small landslide, which then enters a channel, picks up more debris and speed, and finally deposits in a fan at the outlet of the channel.

Debris flows, sometimes referred to as rapidly moving landslides, are the most common type of channelized flow. Lahars are channelized debris flows caused by volcanic eruptions.

Spreads are commonly triggered by earthquakes, which can cause liquefaction of an underlying layer. Spreads usually occur on very gentle slopes near open bodies of water.

Topples and falls are commonly triggered by freeze-thaw cycles, earthquakes, tree root growth, intense storms, or excavation of material along the toe of a slope or cliff. Topples and falls usually occur in areas with near vertical exposures of soil or rock.

Landslide diagrams modified from USGS Landslide Fact Sheet FS2004-3072.

Report a landslide

An INVENTORY OF LANDSLIDES IN OREGON data form has been developed to facilitate the incorporation of slide information from a variety of sources. It was originally developed to inventory the 1996 and 1997 storm events but can be used to input data from other dates. The form is available for download in Word and PDF format at <http://www.oregongeology.com/subLandslide/Inventory/DataForm/dataform.htm>

If you have a large amount of data and/or other means of transfer would be more efficient, please contact Bill Burns directly at (971) 673-1538 or bill.burns@dogami.state.or.us

Please send completed forms to:

DOGAMI
800 NE Oregon St. #28,
Suite 965
Portland, OR 97232



Oregon's debris flow warning system

Oregon's Debris Flow Warning System exists to inform local residents, drivers, road managers, and emergency planners when areas become unsafe because of the threat of debris flows.

Evaluation of debris flow potential will normally be based on forecasted possible rainfall at three key locations along the coast and in the Columbia River Gorge. Each of these locations was selected because of proximity directly west of high debris flow hazard areas. Debris flow warnings are issued by the Oregon Department of Forestry (ODF) primarily when a rainfall threshold at one of these locations is reached or predicted to be reached, particularly if night's obscuring darkness is near.

Warnings are issued through notification of the National Weather Service, Oregon Office of Emergency Management, Oregon Department of Transportation, and Oregon Department of Geology and Mineral Industries. This will trigger broadcast warnings over the National Oceanic and Atmospheric Administration (NOAA) Weather Radio (Frequencies: 162.400, 162.425, 162.450, 162.475, 162.500, 162.550.), NOAA Weather Wire services, Oregon Emergency Response System (OERS), Law Enforcement Data System (LEDS), press releases to the media, and several web sites (see notification services listed under Resources on page 10). The Department of Transportation will also turn on the flashing yellow lights on landslide roadway signs.

Warning mean that intense rainfall that may initiate debris flows is expected within the next predicated hours. During the warning period, people in vulnerable locations may be in imminent threat of serious injury and should take immediate precautionary actions. Areas of steep slopes, canyons, gorges, and the mouths of mountain streams have the highest likelihood of debris flows.

Source: Oregon Debris Flow Warning System Task Force document, 12/2005.

Signs of possible landslide problems:

- Structural deformation such as large foundation cracks, misaligned doors and windows, tilted floors, or sagging decks
- Large, open cracks in driveways, curbs, and roads
- Failing retaining walls
- Arc-shaped cracks in the ground

What can I do to reduce landslide risk around my home?

- If you are looking for or are building a home, avoid siting the structure in a hazardous location.
- Consult a registered geologist or licensed geotechnical engineer if you are considering building or buying on a location with high-risk characteristics.
- Control road or driveway water so it flows away from steep slopes and into storm drains or natural drainages where it will not harm you or your neighbors.

Who should I consult if I have questions about a specific site?

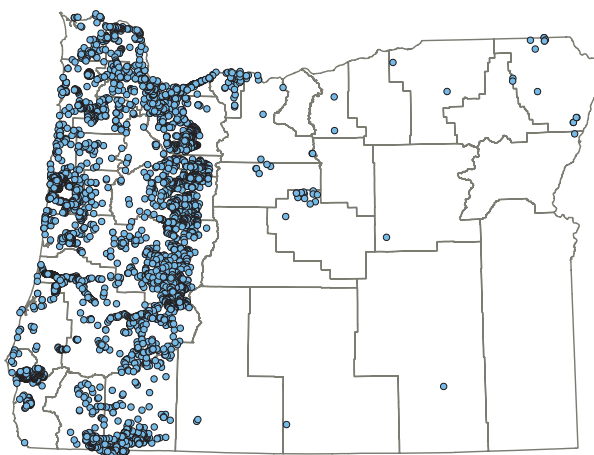
Contact the **Oregon Board of Geologist Examiners** (<http://www.osbge.org/>; phone 503-566-2837) or the **Oregon State Board of Examiners for Engineering and Land Surveying** (<http://osbeels.org/>; phone 503-362-2666) for lists of registered professional consultants available for site-specific evaluations.

When are slides most likely to happen?

- Most recent slides and flows have occurred after several hours or, in some cases, several days of heavy rain or rapid snow melt. Flows may occur hours after the period of the heaviest rain in a storm.
- Earthquakes can cause landslides; if you are on sloping ground or near a riverbank during an earthquake, be alert for landslides.

What should I do during dangerous weather?

- During intense, prolonged rainfall, listen for advisories and warnings over local radio or TV or National Oceanic and Atmospheric Administration (NOAA) weather radio. In western Oregon "intense" rainfall is considered 4% of your average annual rainfall in a 12-hour period during the wet season. East of the Cascade Range "intense" rainfall is 2 inches in 4 hours. Debris flows may occur if such rainfall rates continue.
- Be aware that you may not be able to receive local warning broadcasts in canyons. Isolated, very intense rain may occur outside warning areas. You may want to invest in your own rain gauge. Don't assume highways are safe. Be alert when driving, especially at night.
- Watch carefully for collapsed pavement, mud, fallen rock, and other debris. Be particularly careful in areas marked as slide or rockfall areas. Watch for signs with warnings or road closures.
- Plan your evacuation route prior to a big storm. If you have several hours advance notice, drive to a location well away from steep slopes and narrow canyons.
- Once storm intensity has increased, it may be unsafe to leave by vehicle. Stay alert and awake; you may need to evacuate by foot.
- Listen for loud, unusual sounds. If you think there is danger of a landslide, evacuate immediately—don't wait for an official warning.
- Get away from your home if it is in an unsafe area. Be careful but move quickly. Move away from stream channels.



Landslide know-how

More than 9,500 landslides were reported in Oregon in winter 1996-1997. Protect yourself and your property by knowing landslide warning signs.

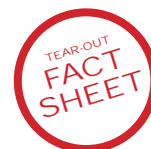
Slope failures in Oregon: GIS inventory for three 1996/97 storm events, DOGAMI Special Paper 34, by R. Jon Hofmeister, 2000

LANDSLIDE INFORMATION RESOURCES

- **Nature of the Northwest Information Center** (<http://www.naturenw.org>), operated by the Oregon Department of Geology and Mineral Industries, carries earthquake and landslide hazard maps and other reports. 800 NE Oregon St., #5, Portland, OR 97232, phone 503-872-2750.
- **Oregon Department of Geology and Mineral Industries** (<http://www.OregonGeology.com>) maps landslides and issues reports and maps.
- **Local city or county emergency managers or planners** may have landslide mitigation information.
- **Association of Oregon Counties** (<http://www.aocweb.org/>) and the **League of Oregon Cities** (<http://www.oregoncities.org/>) work with local government and state agencies to coordinate these efforts.
- **Oregon Department of Forestry Debris Flow Warning System** (<http://egov.oregon.gov/DOF/>) provides current forecasts and warnings.
- **Oregon Natural Hazards Workgroup, Partners for Disaster Resistance and Resilience** (<http://www.oregonshowcase.org/>) provides pre-disaster mitigation planning information.
- **Oregon Department of Transportation** maintains highways and issues 24-hour information about road conditions and road closures. For current conditions, call 1-800-977-6368 or visit <http://www.tripcheck.com>.
- **Oregon Department of Land Conservation and Development** maintains policies that guide local planning for development away from hazardous areas including landslide-prone areas (<http://www.oregon.gov/LCD/HAZ/landslides.shtml>) and also maintains the **Oregon Coast Management Program—Coastal Atlas Hazards Map** (<http://www.coastalatlant.net/learn/topics/hazards/landslides/>).
- **Oregon Department of Consumer and Business Services, Building Codes Division** (<http://www.cbs.state.or.us/bcd/>) provides guidelines for foundations of structures on or adjacent to slopes.
- **USGS National Landslide Information Center** (<http://landslides.usgs.gov/>) has educational information and publications.
- **Geology and engineering departments at Portland State University** (<http://www.pdx.edu>), **Oregon State University, Corvallis** (<http://www.oregonstate.edu>), and **University of Oregon, Eugene** (<http://www.uoregon.edu>) research landslide hazards.

Additional Agencies and Societies

- **Oregon Emergency Management**, <http://egov.oregon.gov/DOHS/DEM/>
- **Federal Emergency Management Agency (FEMA)**, <http://www.fema.gov/hazards/landslides/>
- **USDA Forest Service Pacific Northwest Research Station**, <http://www.fs.fed.us/pnw/>
- **USDA Natural Resources Conservation Service, Soils**, <http://soils.usda.gov/>
- **Association of Engineering Geologists, Oregon section**, <http://www.aegoregon.org/>
- **American Society of Civil Engineers, Oregon section**, <http://www.asceor.org/>
- **Bureau of Land Management, Oregon section**, <http://www.blm.gov/or/>



Oregon LIDAR and landslide publications available now from

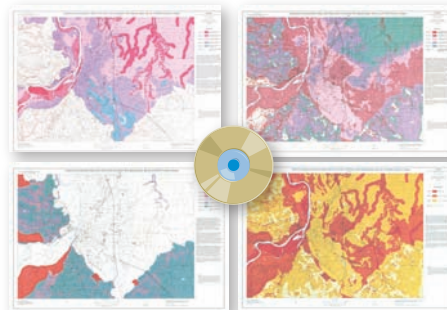


A Geographical Information System (GIS) Data Set of Beach Morphodynamics Derived from 1997, 1998, and 2002 LIDAR Data for the Central to Northern Oregon Coast,

DOGAMI Open-File Report O- 05- 09, by Jonathan C. Allan and Roger Hart, 16 pp., report, data set, and viewer on CD, 2005, \$10.



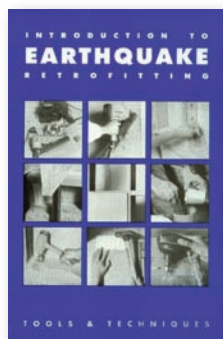
Interim Report: Johnson Creek Landslide Project, Lincoln County, Oregon, DOGAMI Open-File Report O- 06-02, by George R. Priest, Jonathan Allan, and Alan Niem, 2006, CD, \$10.



Relative earthquake hazard maps of Salem East and Salem West quadrangles, Marion and Polk Counties, Oregon, DOGAMI Geologic Map Series 105, by Y. Wang and W. J. Leonard, 10 pp., 4 plates (liquefaction susceptibility, amplification susceptibility, landslide susceptibility, and relative earthquake hazard maps), scale 1:24,000, 1996, CD, \$10.



Landslide Loss Estimation Pilot Project in Oregon, DOGAMI Open-File Report O-02-05, by Yumei Wang, Renee D. Summers, and R. Jon Hofmeister, 2002, CD, \$10.



Introduction to Earthquake Retrofitting: Tools and Techniques, by Charles Smith and Cindy Furukawa, Building Education Center, Berkeley, CA, 1996, \$9.95.

A complete list of DOGAMI publications can be found online at: www.OregonGeology.com.

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Places to see

Ochoco Reservoir: The white outline marks Quaternary landslide scarps and deposits exposed along US highway 26 on the north shore of Ochoco Reservoir. The landslide material is derived from the south-dipping, 27.54 ± 0.36 million-year-old Ochoco Rhyolite (John Day Formation). Jasper and agate are found by rock hounders at the base of the rhyolite. Contact the Ochoco National Forest for further details. The Three Sisters volcanoes and Cascade crest are visible on the skyline.



Photos: Jason D. McClaughry, DOGAMI Learn more about Oregon's geology by going online at www.OregonGeology.com.

Boulder Park campground and trail head, near Wallowa State Park, accessed by Forest Service roads: This landslide scarp and deposit are left from the 1984(?) slope-failure originating on the lateral moraine in the upper right of the photograph. West Eagle Creek (out of view) was temporarily dammed by the slide and has since cut back down through the slide toe. Pleistocene glacial sediment in the Blue and Wallowa Mountains of northeast Oregon constitute a significant source of debris flow material that can be easily reworked and transported down slope by flash floods.

