PROTOCOL FOR INVENTORY MAPPING OF LANDSLIDE DEPOSITS FROM LIGHT DETECTION AND RANGING (LIDAR) IMAGERY

by William J. Burns and Ian P. Madin

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Cover image: (left) Hillshade image showing area around Oregon Highway 213 and Newell Creek Canyon in Oregon City, Oregon, and (right) same image draped with landslide polygons mapped using the protocol developed in this paper.

State of Oregon
Department of Geology and Mineral Industries
Vicki S. McConnell, State Geologist

Special Paper 42

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NOTICE

The Oregon Department of Geology and Mineral Industries is publishing this paper because the subject matter is consistent with the mission of the Department. The paper is not intended to be used for site specific planning. The protocol described in this paper cannot serve as a substitute for site-specific investigations by qualified practitioners. Site-specific data may give results that differ from those which would result from use of the protocol described in this paper. The hazards of an individual site should be assessed through geotechnical or engineering geology investigation by qualified practitioners.

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1.0 EXECUTIVE SUMMARY

Landslides are one of the most widespread and damaging natural hazards in Oregon. To reduce losses from landslides, areas of landslide hazard must first be identified. The initial step in landslide hazard identification is to create an inventory of past (historic and prehistoric) landslides. The inventory can be used to create susceptibility maps that display areas likely to have landslides in the future. After landslide hazards have been identified on inventory and susceptibility maps, the risk can be quantified and mitigation projects can be prioritized and implemented.

To create a consistent landslide inventory for Oregon the Oregon Department of Geology and Mineral Industries (DOGAMI) developed the protocol described in this paper. We developed the protocol using the best available data (lidar imagery) to ensure the most accurate results. The Oregon Lidar Consortium plans to continue collecting lidar data so that mapping using this protocol can continue throughout Oregon. An additional benefit of creating the protocol and its associated map template and geodatabase is expeditious mapping and publication of landslide inventory data.

To begin the extensive undertaking of mapping existing landslides throughout Oregon, a pilot project area was selected to compare remote sensing data/images for effectiveness (Burns, 2007). Two key findings from this pilot study were: 1) the use of the light detection and ranging (lidar) data resulted in identification of 3 to 200 times the number of landslides found with the other data sets, and 2) the accuracy of the spatial extent of the landslides identified was greatly improved with lidar data. Thus, lidar-derived digital elevation models were selected as the base from which to create the landslide inventory described in this paper. The inventory mapping protocol consists of six steps:

1. Acquire and visualize base data
2. Map spatial and tabular data in a geodatabase
3. Verify mapped data in the field
4. Display landslide inventory data using a template map
5. Understand the limitations of the data and recommendations for use
6. Use the landslide inventory data products

The protocol and products produced using this protocol can be used to help Oregon communities become more resilient to the impacts of landslide hazards.

2.0 INTRODUCTION

Landslides are one of the most devastating natural, and sometimes human-induced, disasters. Worldwide, they cause billions of dollars in property damage and thousands of deaths every year (Hong and others, 2007). Landslides in the United States cause an average of 25–50 deaths and over $2 billion in economic losses annually (Turner and Schuster, 1996; Spiker and Gori, 2003).

In Oregon, landslides pose significant threats to people and infrastructure. As population growth continues to expand and as development on landslide susceptible terrain increases, greater losses are likely to result (Figure 1). Most of Oregon's landslide damage has been associated with severe winter rain storms — landslide losses exceed $100 million in direct damage (such as the February 1996 event) (Wang and others, 2002). However, landslides are also a chronic hazard in Oregon; annual average maintenance and repair costs for landslides in Oregon are estimated at over $10 million (Wang and others, 2002). Many parts of Oregon are susceptible to landslides induced by earthquake shaking, and losses associated with sliding in moderate-to-large earthquakes are likely to be significant. Volcano-induced landslide hazards are also potential threats to parts of Oregon.

DOGAMI recently researched the best remote sensing data set (photos, photogrammetric elevation data, lidar elevation data) to use as a primary tool for systematic mapping of landslides in Oregon (Figure 2; Burns, 2007). The conclusion of this pilot study was that lidar was overwhelmingly better than other available remote sensing data sets (e.g., 30-m shuttle data, 10-m national elevation data set, aerial photos).

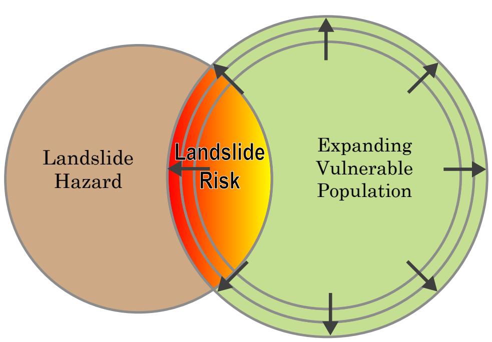


Figure 1. Risk diagram shows the overlap of landslide hazard and vulnerable population (modified after Wood, 2007).

2.1 INTENDED AUDIENCE AND DOGAMI ROLE

This protocol was developed so that DOGAMI and others can produce consistent lidar-based landslide inventory maps quickly and consistently. The existing information is not comprehensive, but future efforts can build on and refine the data and protocol.

The intended audience of this paper is primarily DOGAMI scientists but also includes government, industry, and university scientists who are interested in producing standardized landslide inventory maps, and end users of maps. DOGAMI encourages the use of this protocol and intends to have it established as the Oregon standard for geographic information system (GIS) based landslide inventory through the state Geospatial Enterprise Office (GEO; http://www.oregon.gov/DAS/EISPD/GEO/index.shtml) Framework program. DOGAMI plans to publish landslide inventory maps that are developed using this protocol. Publication of maps produced by non-DOGAMI staff will likely require detailed review by a DOGAMI employee to ensure consistency.

In addition to maps for specific areas, data published by DOGAMI using this protocol will be used to update data in the Statewide Landslide Information Layer for Oregon (SLIDO) (http://www.oregongeology.org/sub/slido/index.htm).

2.2 BACKGROUND

In 2005, DOGAMI began a collaborative landslide research program with the U.S. Geological Survey (USGS) Landslide Hazards Program to identify and understand landslides in Oregon. A pilot project area was selected in order to compare remote-sensing data sets for effectiveness. The data sets compared included (Burns, 2007):

- 30-m (98 ft) digital elevation model (DEM) from the Shuttle Radar Topography Mission (Figure 2a)
- 10-m (33 ft) DEM derived from USGS topographic quadrangles (Figure 2b)
- photogrammatic and ground-based 7-m (23 ft) interval contour data (Figure 2c)
- stereo aerial photographs from 1936 to 2000

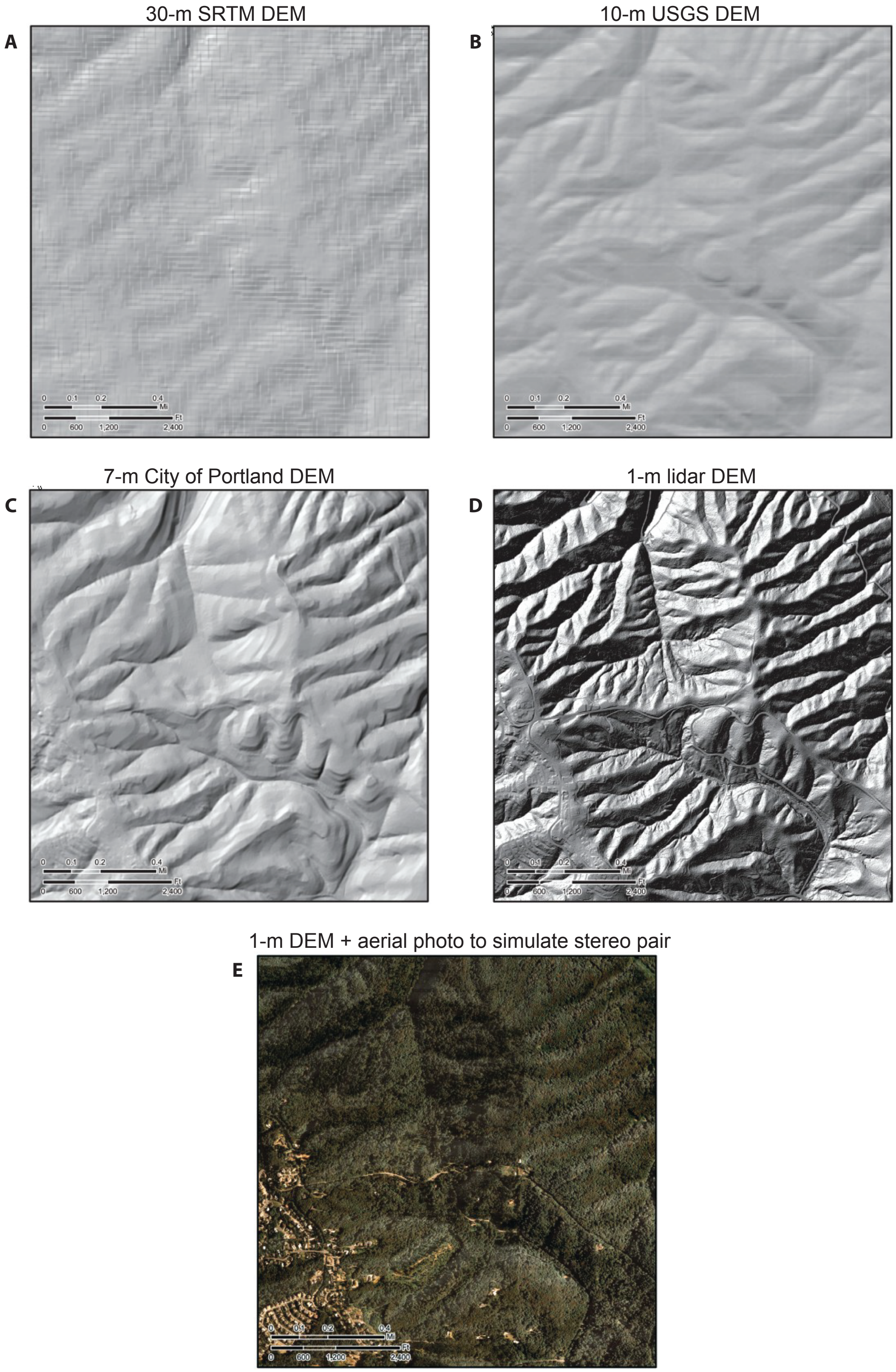


Figure 2. Comparison of five remote-sensing data sets for the same area. SRTM is Shuttle Radar Topography Mission; USGS is U.S. Geological Survey. The aerial photo (e) is draped over a digital elevation model (DEM) so that it simulates the three-dimensional view provided by a stereo-pair photograph.

- lidar imagery with an average of one data point per square meter (3.2 ft^2) and with a vertical accuracy of about 15 cm (6 in) (Figure 2d)

Two key findings of the pilot project were: 1) use of lidar data resulted in identification of 3 to 200 times the number of landslides identified using the other data sets, and 2) mapping the spatial extents of landslides identified from lidar data was easier and more accurate compared to other mapping methods.

When examining the results of the comparison of remote-sensing data, several debris flow fans at the mouths of channels or potential channelized debris flow deposits were identified with serial stereo-pair aerial photos, which did not get identified on the lidar-derived DEMs. Dense development has taken place in Oregon in the last 40 years, which can mask landslide features, especially if major earthwork has taken place. In most of the populated areas of Oregon, if historic air photos are available, at least one review of (greater than 40 years old) photos should be undertaken (Burns, 2007).

When developing accurate large-scale landslide inventory maps, we recommend the following minimal steps:

1. All previously identified landslides from geologic maps, landslide studies, and other local sources should be compiled.
2. The mapper should have experience identifying all types and ages of landslides within the area being studied.
3. Lidar data should be used to identify landslides and accurately locate the extents of previously mapped landslides (from step 1).
4. An orthophoto of similar age to the lidar data should be used to minimize misidentification of man-made cuts and fills as landslides.
5. The mapper should use at least one set of historical stereo-pair aerial photography to locate landslides in the area being studied.
6. Nonspatial data should also be collected at the time of the mapping so that a comprehensive database can be formed. Nonspatial data should generally include, for example, confidence of interpretation, movement class, and direction of movement. The nonspatial data gathered for this protocol are described in detail in section 5.2.2 of this paper.
7. A comprehensive check, including technical review of mapped landslides and field checks where possible, of spatial (map) and nonspatial data should be developed and implemented.

3.0 PREVIOUS LANDSLIDE INVENTORIES

The first statewide database of landslides for Oregon was prepared after the severe storm events in 1996 and 1997 and was published as DOGAMI Special Paper 34 (Hofmeister, 2000). The database incorporated information compiled by a number of federal, state, and local data sources; hence, the quality of the data varies considerably. The database provides locations for approximately 9,500 landslides (Figure 3) that occurred during 1996-1997. Most mapped locations are points, so in many cases the spatial extent of the landslides is unknown. Five deaths are directly attributed to landslides during 1996 (Hofmeister, 2000).

As shown in Figure 3, almost all of the landslides in the database are located west of the Cascade Mountains. This is because most of these landslides were triggered by intense rain events and/or rain-on-snow events that generally did not impact the eastern portion of the state (Burns and others, 1998).

From research performed by DOGAMI and the USGS during 2005-2006 and from the recommendation of Burns (2007), DOGAMI compiled the Statewide Landslide Information Database of Oregon, release 1 (SLIDO-1; Figure 4) (Burns and others, 2008) a statewide database of the majority of previously identified landslides from geologic maps, previous landslide studies, and other local sources. SLIDO includes digital landslide mapping derived from 257 published geologic reports and geologic hazard studies primarily by the USGS and DOGAMI, along with regional studies by the U.S. National Forest Service (USFS) and theses studies in the state. Most of the maps used to compile SLIDO were geologic maps that have widely variable quality and completeness in regard to mapping of landslides and related features. This is apparent in the numerous map boundary faults on the full-size map.

A third statewide inventory of landslides from the Oregon Department of Transportation (ODOT) is now partially available in a GIS (K. Castelli and C. Mohney, unpublished data, unstable slopes inventory program, ODOT, 2008). This inventory of historic landslides is limited to state and interstate highways; however, it includes detailed information at each location.

Other landslide data that should be acquired and reviewed during the landslide inventory process is from the local county and city in which the mapping is being done. These data are often very useful for identifying historical landslides.

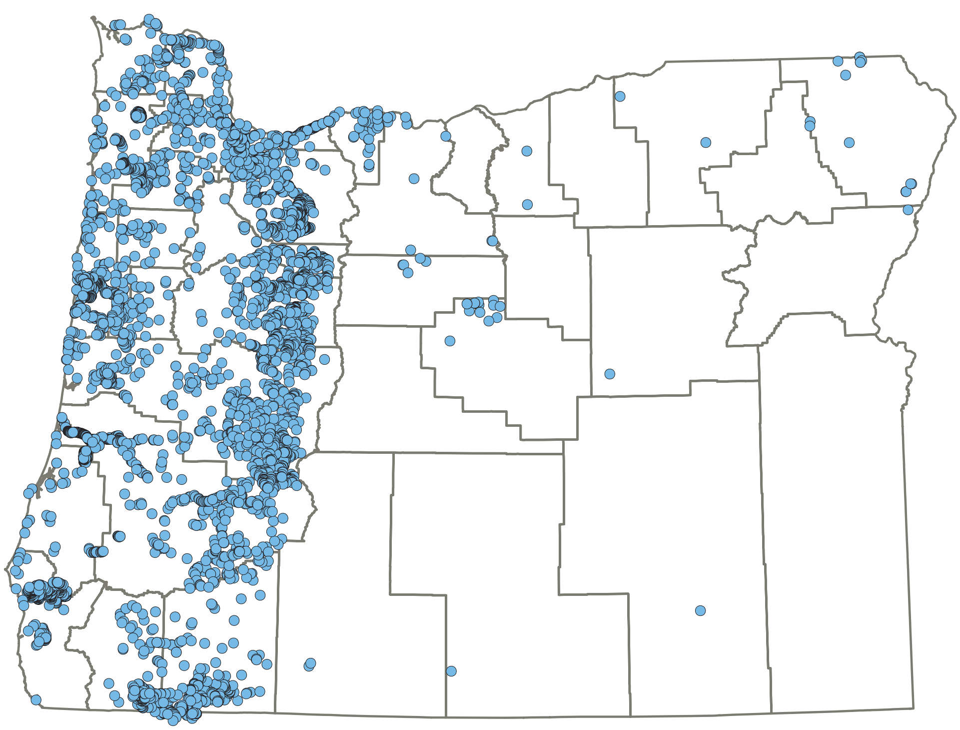


Figure 3. Map of a landslide database (blue dots) consolidated after severe storms in 1996-1997 (Hofmeister, 2000).

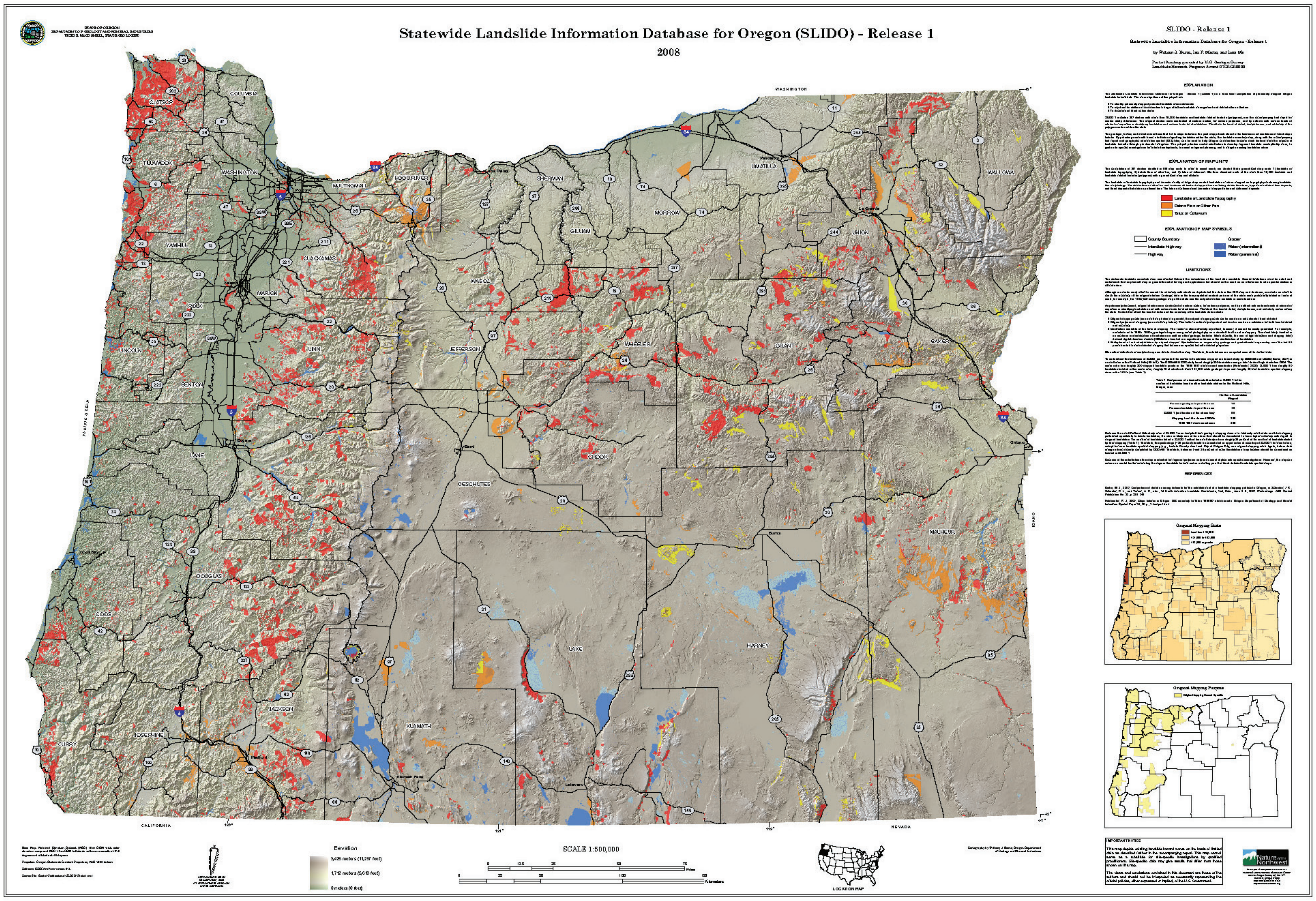
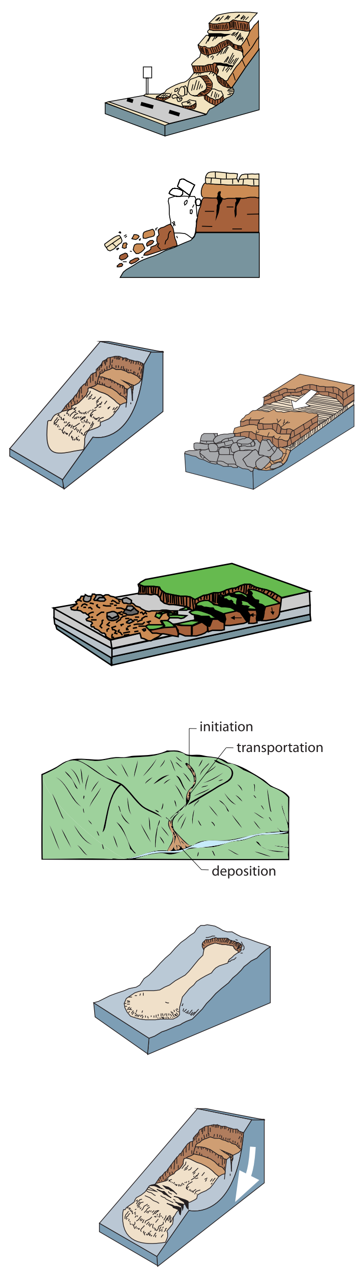


Figure 4. The Statewide Landslide Information Layer for Oregon (SLIDO) release 1 (Burns and others, 2008) is a database of the roughly 15,000 Oregon landslide deposits identified in published literature. A data map shows fans (red polygons), debris flow fans (orange polygons), and landslide-related deposits (yellow polygons) including colluvium and talus.

4.0 LANDSLIDE TYPES

The general term "landslide" refers to a range of mass movements including rock falls, debris flows, earth slides, and other mass movements (Varnes, 1978). Different types of landslides have different frequencies of movements, triggering conditions, and very different resulting hazards.

All landslides can be classified into six types of movement (Figure 5): 1) falls, 2) topples, 3) slides, 4) spreads, 5) flows, and 6) complex. Most slope failures are complex combinations of these distinct types, but the generalized groupings provide a useful means for framing discussion of the type of hazard associated with the



Falls are near-vertical, rapid movements of masses of materials, such as rocks or boulders. The rock debris sometimes accumulates as talus at the base of a cliff.

Topples are distinguished by forward rotation about some pivotal point, below or low in the mass.

Slides are downslope movement of soil or rock on a surface of rupture (failure plane or shear-zone).

- **Rotational** slides move along a surface of rupture that is curved and concave.
- **Translational** slides displace along a planar or undulating surface of rupture, sliding out over the original ground surface.

Spreads are commonly triggered by earthquakes, which can cause liquefaction of an underlying layer and extension and subsidence of commonly cohesive materials overlying liquefied layers.

Channelized Debris Flows commonly start on a steep, concave slope as a small slide or earth flow into a channel. As this mixture of landslide debris and water flows down the channel, it pick ups more debris, water, and speed, and deposits in a fan at the outlet of the channel.

Earth Flows commonly have a characteristic "hourglass" shape. The slope material liquefies and runs out, forming a bowl or depression at the head.

Complex landslides are combinations of two or more types. A common complex landslide is a slump-earth flow, which usually exhibit slump features in the upper region and earth flow features near the toe.

Figure 5. Types of landslide movements (modified after Highland, 2004).

landslide, the landslide characteristics, identification methods, and potential mitigation alternatives.

Movement type should be combined with other landslide characteristics such as type of material, rate of movement, depth of failure, and water content in order to more fully understand the landslide behavior. Many landslides exhibit common features as shown in Figure 6. For a more complete description of the different types of landslides, see U.S. Transportation Research Board Special Report 247 (Turner and Schuster, 1996), which has an extensive chapter on landslide types and processes.

One type of landslide that is often life threatening is the channelized debris flow or "rapidly moving landslide." Debris flows often initiate on a steep slope, move into a steep channel (or drainage), increase in volume by incorporating channel materials, and then deposit material, usually at the mouth of the channel on existing fans. Debris flows are also commonly mobilized by other types of landslides that occur on slopes near a channel. They can also initiate within channels from accelerated erosion during heavy rainfall or snow melt.

Hill slope areas that have failed often remain in a weakened state, and many of these areas tend to fail repeatedly over time. A channel with a debris flow fan at its mouth indicates a history of debris flows in that channel. The formation of talus slopes indicates that numerous rock falls have occurred. Large landslide complexes may have moved dozens of times over thousands of years, with long periods of stability punctuated by episodes of movement. Thus previously failed areas are particularly important to identify, as they maybe susceptible to future instability. In some cases, areas that have previously failed have subtle topographic morphology, making them difficult to identify.

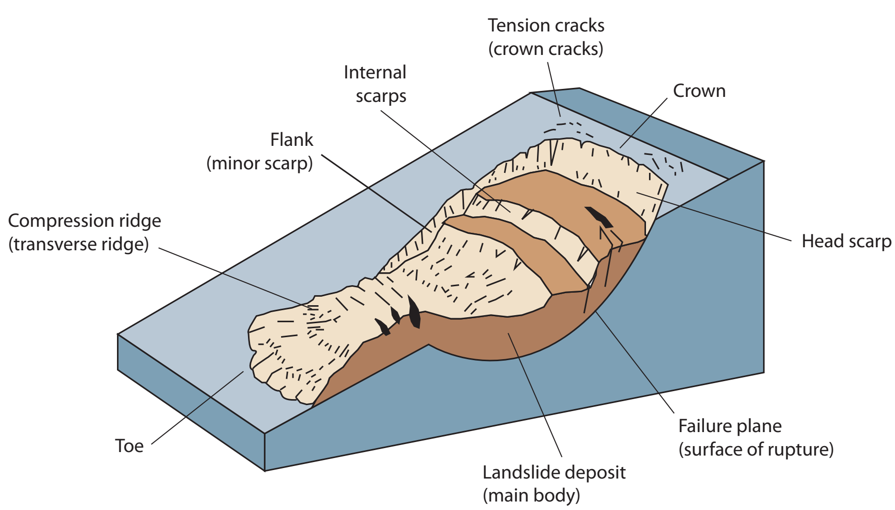


Figure 6. Block diagram of a slump-earth flow showing common features (modified from Highland, 2004).

5.0 METHODOLOGY

The method employed to identify landslide areas in this study is divided into four main steps:

1. Acquire and visualize base data including:
   - DEM derived from lidar data,
   - Slope map derived from lidar data,
   - Orthorectified aerial photo of similar age to the lidar data,
   - Previous landslide inventories or other data on landslides within the proposed mapping area, and
   - Geologic map.
2. Map landslide spatial data and tabular data by
   - Setting up the computer workspace necessary for mapping and
   - Mapping at multiple scales.
3. Review and field verify spatial and tabular data.
4. Create one-quarter-quadrangle landslide inventory maps.

5.1 ACQUISITION AND VISUALIZATION OF BASE DATA

In the last half decade or so, very high resolution, high-accuracy DEMs developed using lidar data have become available for some parts of Oregon. These new data give us a much better image of the surface of Earth, allowing the identification of topographic features associated with landslides, such as concave slope (closed) depressions, steep or vertical scarps, shear zones located along the flanks of a landslide, and transverse ridges, snouts, and toes (Turner and Schuster, 1996). Recognizing these topographic features allows identification of landslides with a high level of certainty and accurate mapping. In the past, most of the highly accurate landslide maps have been created by combining aerial photography and extensive field surveys. For this mapping protocol, bare-earth DEMs derived from lidar data are the essential tool.

The lidar-derived DEM should be first viewed as a shaded relief map or hillshade map with a sun azimuth of 315° and altitude of 45° as shown in Figure 7. Because the grayscale DEM can become confusing when a mapper is scanning the map at various scales, we recommend adding an elevation color profile to help the mapper visualize the upslope and downslope direction easily at all scales (Figure 7).

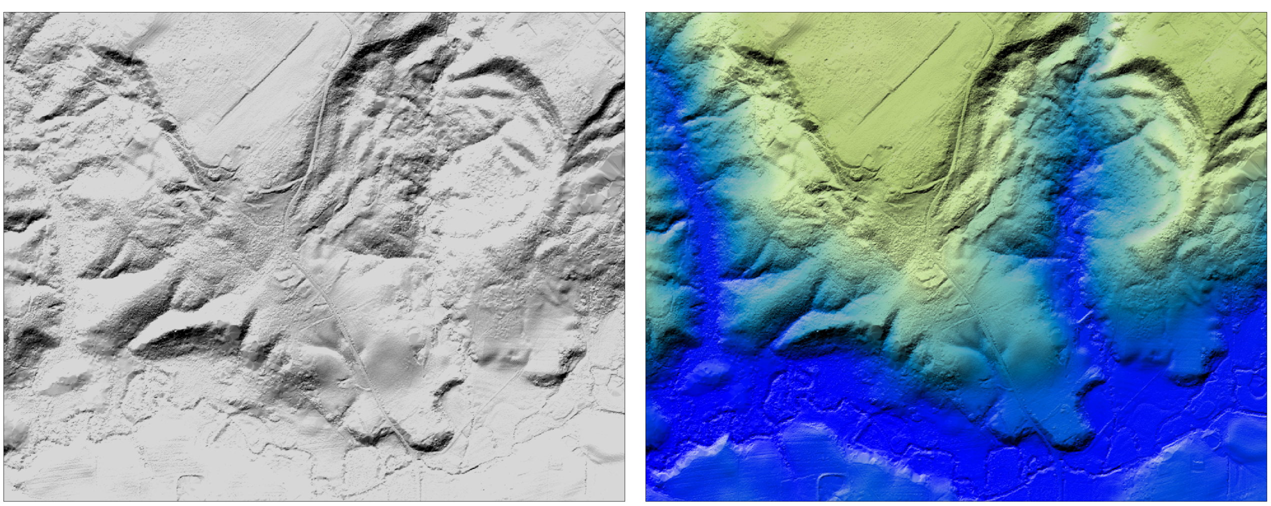


Figure 7. Lidar-derived digital elevation model (DEM) viewed as (left) a hillshade in grayscale with a sun azimuth of 315° and altitude of 45° and (right) with a color profile (blue for lower elevations and green for higher elevations).

Previous mapping of landslides using lidar imagery in Seattle, Washington, by the USGS found that hillshade images had to be viewed with at least three sun azimuths to provide suitable lighting conditions for different slope orientations (Schulz, 2004). Rather than viewing the same area at the same scale with three different hillshades, we recommend the following:

1. Apply 50% transparency to the colored hillshade (the original colored hillshade before transparency is applied is shown in Figure 7, right).
2. Create a slope map with all slopes greater than 45° in a dark gray.
3. Layer the slope map beneath the colored hillshade and apply 10% transparency to the slope map.

The resulting image is shown in Figure 8 (left). In some instances, it may be advantageous to eliminate the hillshade and just use the combined slope map and DEM with color. We also found that adding colors to the slope map at particular slope intervals helped identify slope breaks and other topographic features.

To further enhance the morphology and to assist in locating and accurately defining landslide features, topographic contours derived from the lidar DEM can be overlaid on the hillshade/slope map (Figure 8, right). Contours are particularly helpful in identifying the subtle morphology associated with debris-flow fans. The images in Figure 8 are the two main views that should be used to identify topographic features that define and outline landslides.

In addition to lidar-derived imagery, an orthophoto of similar age to the lidar data should be used to help differentiate between man-made and natural landforms (Figure 9, top). In the lower images in Figure 9, three features that could be mistaken as landslides are identified (ovals); however, upon review of the orthophoto (lower right) all three features appear to be man-made. The man-made features are cuts and fills that can resemble the head scarp and toe morphology of a landslide.

Additional base data layers that should be compiled and added to the mapping project are previous landslide inventories or other data on landslides within the proposed mapping area. As a minimum this should include any landslides contained in DOGAMI Special Paper 34 (Hofmeister, 2000) and the latest version of SLIDO (release 1, Burns and others, 2008) (Figure 10).

We found that to zoom and pan easily at varying scales in a GIS environment using the lidar-derived images and the other recommended layers, the lidar-derived images had to be separated into sections roughly one quarter the size of a 7.5-minute quadrangle. Section size is a function of computer power and type of GIS software, and the appropriate size may vary for each user environment.

The final base layer that should be examined is geologic map. The Oregon Geologic Database Compilation is an assemblage of the best available geologic maps for the state of Oregon in GIS (Jenks and others, 2008). The project is over 75% finished and expected to be complete for the entire state by 2009.

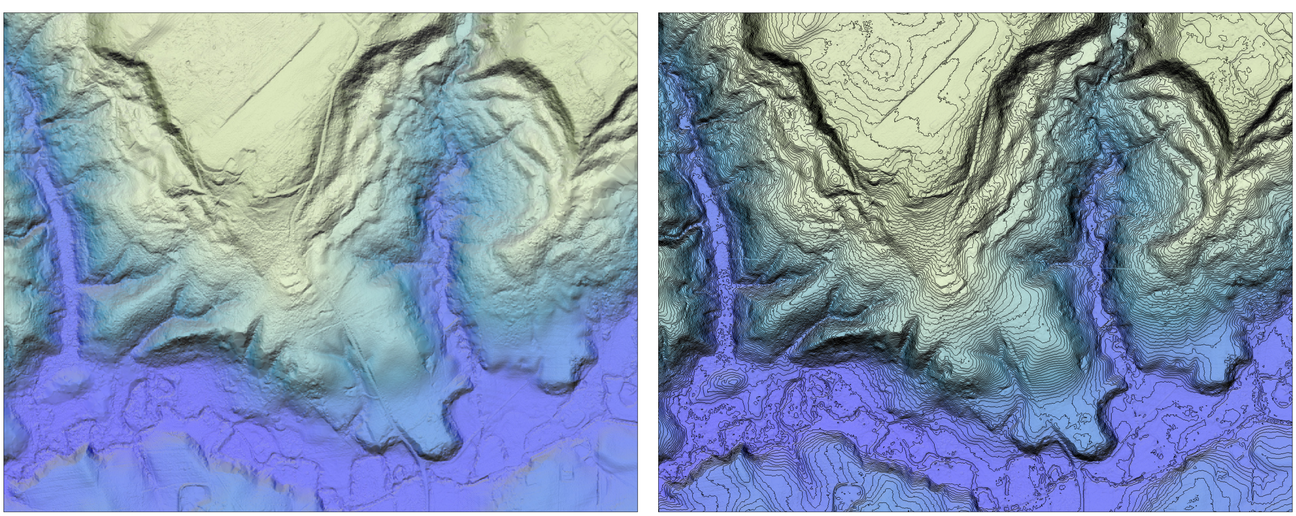


Figure 8. (left) Colored hillshade draped on slope map and (right) with contour lines.

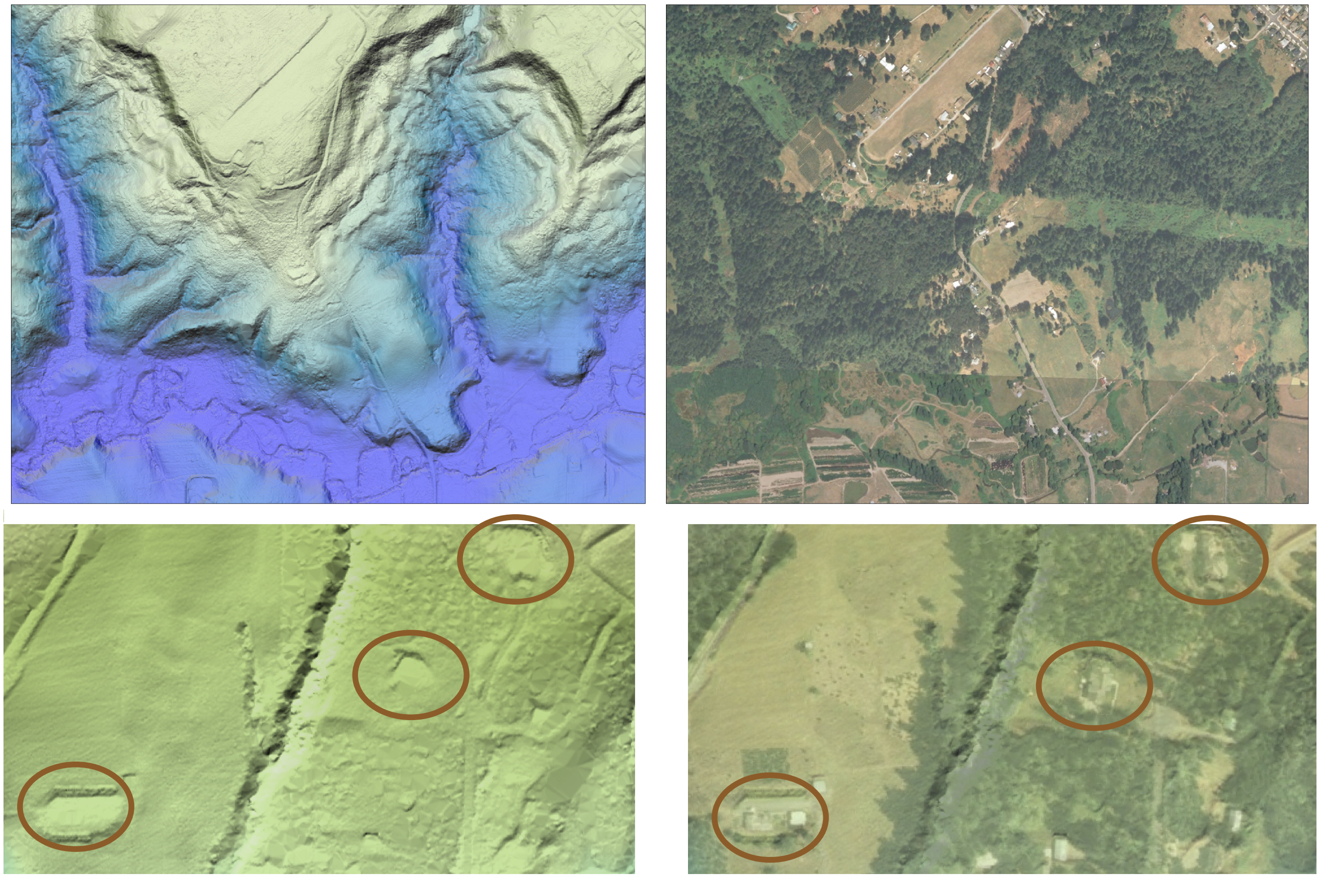


Figure 9. (upper left) Color hillshade-slope map and (upper right) orthophoto. (lower left) Example of three landforms resembling landslide morphology identified by brown circles. (lower right) The same three areas identified as man-made features on an orthophoto. (Note that the lower images are not from the same area as upper images.)

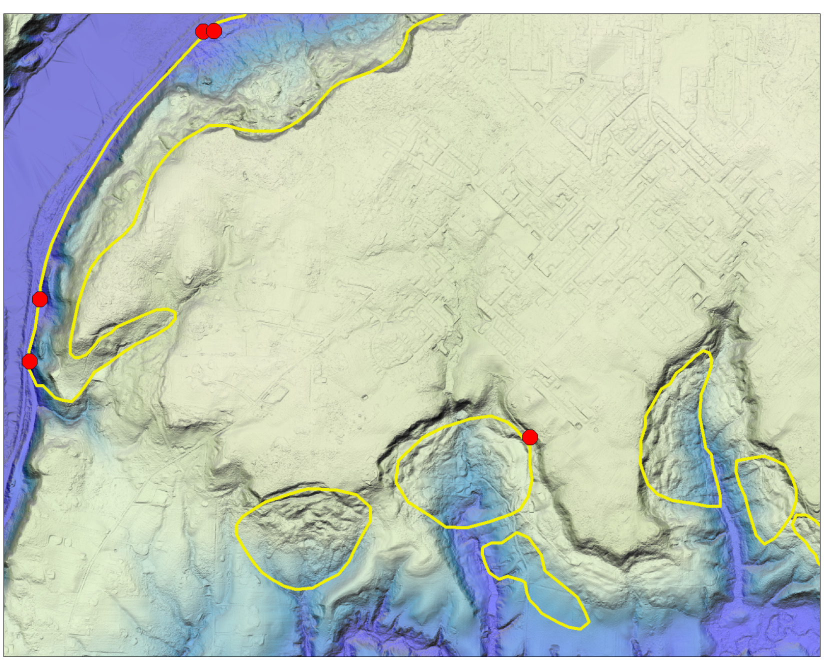


Figure 10. Previously mapped landslide points from Special Paper 34 (Hofmeister, 2000) (red points) and landslide extents from SLIDO-1 (Burns and others, 2008) (yellow polygons).

5. 2 MAPPING LANDSLIDES: SPATIAL DATA AND TABULAR DATA

The method employed to identify landslide areas in this study uses two kinds of data: 1) spatial data and 2) tabular data. Spatial data are data that can be mapped as points, lines, or polygons. Tabular data are descriptive data, usually in text or numeric form, stored in rows and columns in a database and linked to spatial data.

To facilitate data collection, a geodatabase template was developed as part of this protocol. The template includes empty feature classes for deposits, scarp flanks, scarps, and photos. A screenshot of the structure as set up in Environmental Systems Research Institute, Inc. (ESRI) ArcCatalog™ is shown in Figure 11. The geodatabase includes relationship classes between the feature classes. The template includes all fields for the tabular data (Table 1 and Appendix A), located in the Deposits feature class. Individual mappers who use this template can then easily transfer their data into a master geodatabase. Appendix B is a guide for setting up and using the geodatabase template.

5.2.1 Spatial Data

Spatial data that should be compiled includes the following:

- Polygon (outline) of the mapped landslide deposit (including debris flow fans and talus extent)
- Polygon (outline) of the landslide head scarp and flanks
- Line of the uppermost extent of the head scarp
- Lines of internal scarps

All four of these items may not be present at every landslide. For example, many debris flow fan deposits are commonly mapped without the other spatial data. These polygons and lines are illustrated as block diagrams with a corresponding map view in Figure 12. The examples shown in Figure 12 are applicable to most landslide types, except channelized debris flows and rock fall/topples, which are illustrated in Figure 13. These landslides and landslide features should be digitized/mapped using GIS software and either an interactive pen display monitor or mouse. An orthophoto of similar age to the lidar data should be inspected during the digitizing/mapping process to assure that man-made features such as cuts and fills are not misidentified as landslides and landslide features (Figure 9).

It is very helpful to use a grid layer to help keep track of areas already mapped (Figure 14). While digitizing/mapping an area, the previously mapped landslide inventories available in the area should also be inspected and confirmed or corrected.

Landslides and landslide features vary in size, so mapping should be done at several different scales. We recommend scanning the area at the following scales:

- 1:24,000 (the native scale of standard printed 7.5-minute topographic quadrangles)
- 1:10,000
- 1:4,000

After landslides have been mapped at the different scales, all lines should be relocated at a scale of 1:4,000 to ensure that all spatial data (lines) have been mapped consistently.

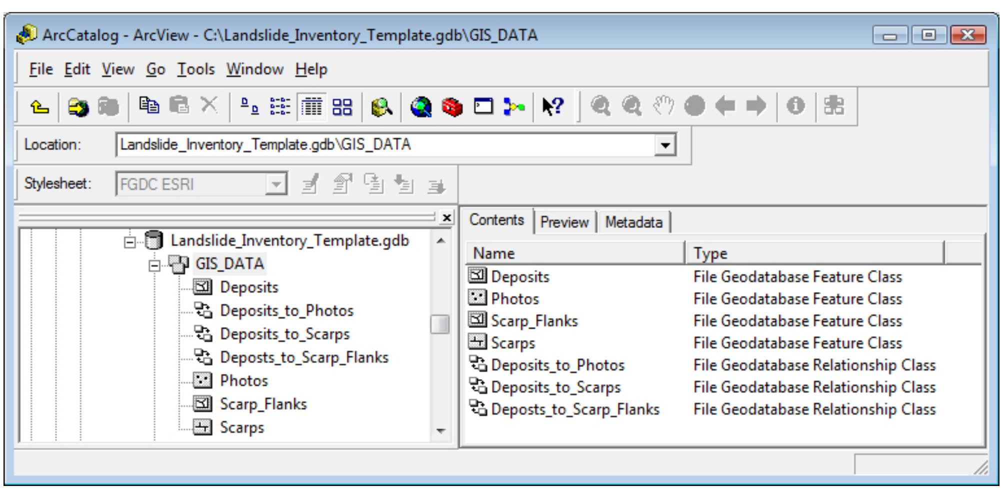


Figure 11. Screenshot of Environmental Systems Research Institute, Inc. (ESRI) ArcCatalog™ interface showing landslide geodatabase template structure developed for this protocol.

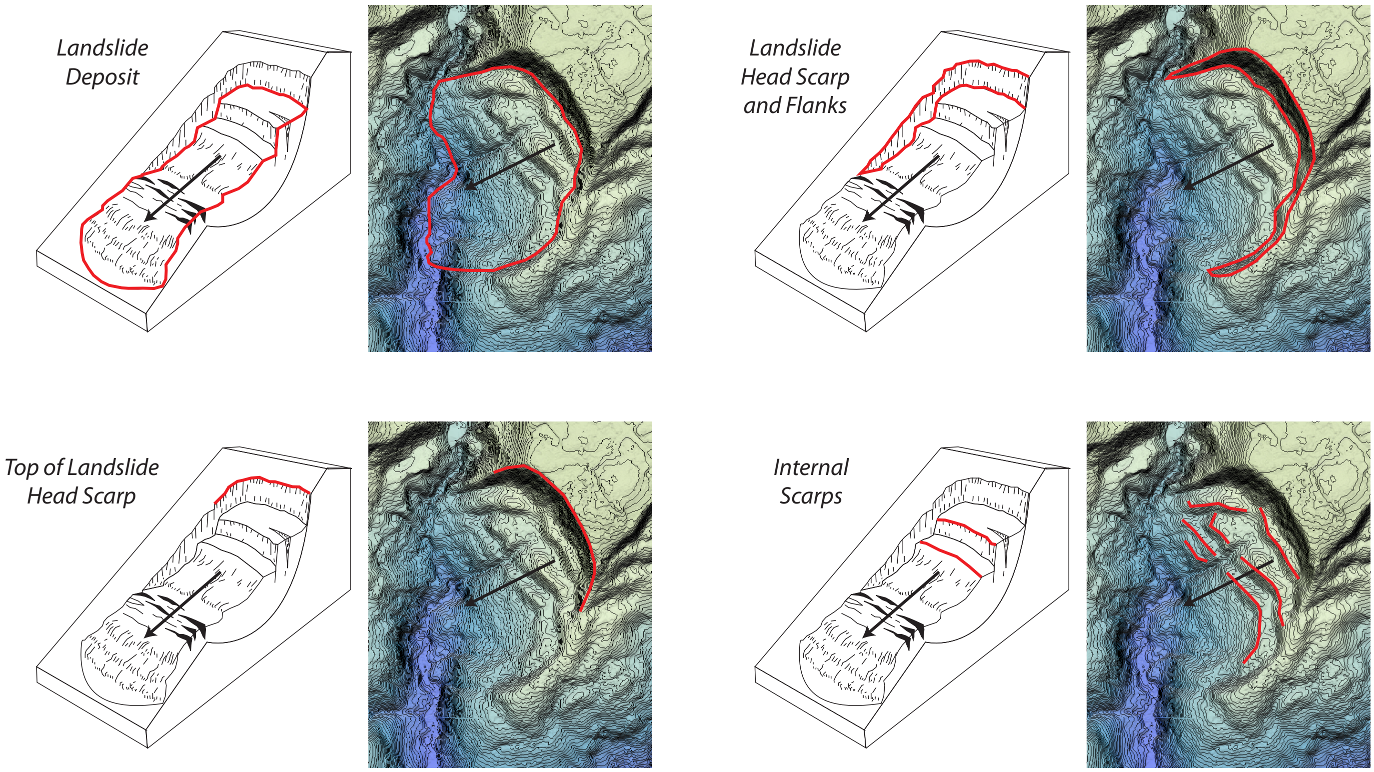


Figure 12. Block diagrams and map views showing the four kinds of spatial data compiled for each landslide.

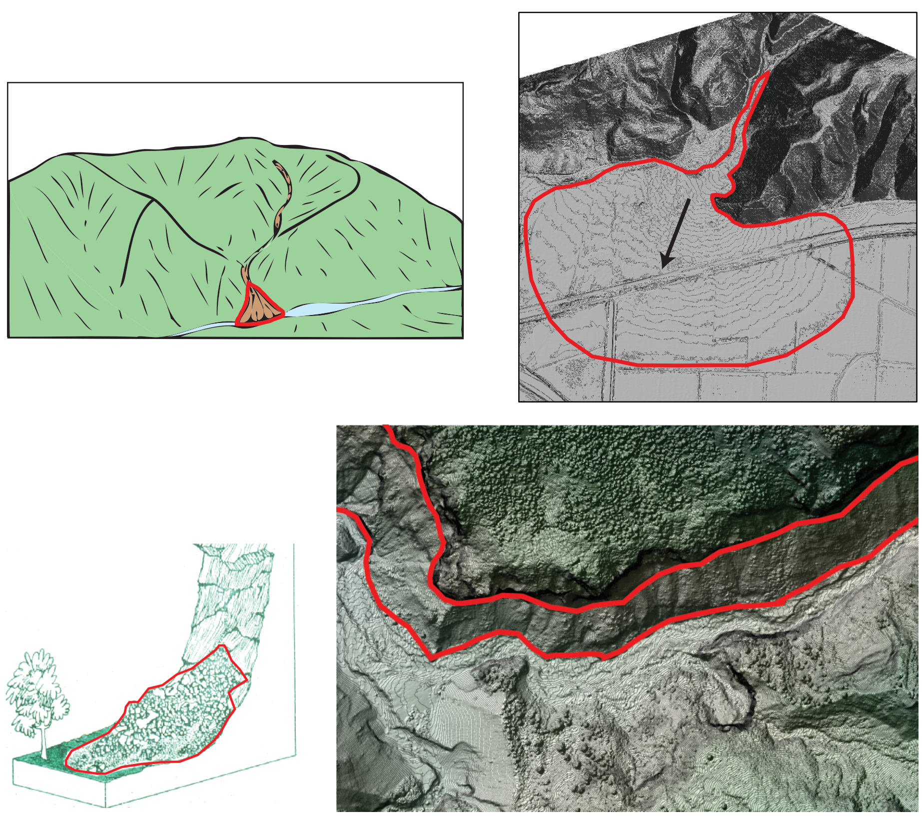


Figure 13. Block diagrams and map views of (top) channelized debris-flow fan and (bottom) rockfall/topple talus.

Landslide mapping using DEMs derived from lidar in the Seattle, Washington, area was done systematically at several scales (Schulz, 2004). If historic air photographs are available for the mapping area, at least one review of photographs more than 40 years old should be undertaken (Burns, 2007). As a last step in compiling spatial data, all GIS data should be processed to remove redundant or unneeded data and topological errors.

Related to mapping scale and confidence (discussed later in this section) is the accuracy and precision of the mapped landslide deposits and features. Analysis of the accuracy and precision is very difficult, especially when there is no definitive map for comparison. Therefore, we assume that the areas mapped following this protocol are landslide deposits and features.

As previously discussed, accuracy of mapped landslides identified from lidar data is greatly improved when compared with other mapping methods, especially if the recommendations for visualization of base data in this protocol are followed (Burns, 2007). However, the accuracy will still vary with the skill and care of the individual mapper and the quality of the lidar data.

Precision will also be improved if the recommendations in this protocol are followed. However, precision is a function of the visual strength and sharpness (or clarity) of the topographic features used to identify the landslides and the related quality of the lidar data (DEM grid size). The limitations of the maps produced following this protocol are discussed in section 7.

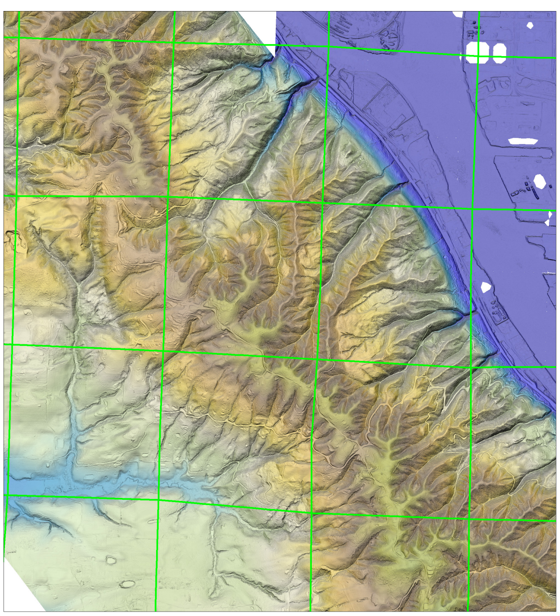


Figure 14. Example of a grid layer (green) used to keep track of mapped areas.

5.2.2 Tabular Data

Each kind of spatial data should also have several attributes (tabular data) linked to the polygons or lines (Table 1). Appendix A lists the tabular data fields.

5.2.2.1 Type of movement

Each landslide should be classified into one the following types of movement (Figure 5): 1) slides 2) flows, 3) spreads, 4) topples, 5) falls, 6) complex.

5.2.2.2 Classification of material and movement types

Landslides should be differentiated by the kinds of material involved and the mode of movement. A classification system based on these parameters was developed by Varnes (1978) and is shown in Table 2. To assist the mapper, block diagram examples and detailed descriptions of some of the most common types of landslides in Oregon are given in Figure 5.

5.2.2.3 Confidence of landslide identification

Each landslide should be classified according to a "confidence" the mapper assigns based on the likelihood that the landslide actually exists (Irvine and others, 2007). Landslides are mapped based characteristic topographic features, and the confidence of the interpretation is based on the visual clarity of the features. As a landslide ages, weathering (primarily through erosion) degrades the topographic features produced by landsliding. With time, landslide features may become so subtle that they resemble features produced by geologic processes and conditions unrelated to landsliding.

Most landslides have several different types of topographic features associated with them (Figure 6). A good way to define certainty is through a simple point system (Table 3) associated these features. The point system in this protocol is based on a ranking of four primary landslide features with 0 to 10 points per feature, with zero points for an unidentifiable feature and 10 points for a very clearly identifiable feature. For example, if the head scarp and toe of a landslide were clearly identifiable in the lidar DEM, the mapper would apply 10 points for the head scarp and 10 points for the toe, equaling 20 points, which would be associated with a moderate certainty of identification.

Table 1. Tabular data fields in landslide geodatabase.

Field Name	Brief Description
QUADNAME	7.5 minute quadrangle name
UNIQUE_ID	"QUADNAME"_"ID"*
TYPE_MOVE	type of movement
MOVE_CLASS	movement classification name
MOVE_CODE	movement classification code
CONFIDENCE	confidence of identification
AGE	estimated age
DATE_MOVE	date of last known movement
NAME	landslide name
GEOL	geologic unit
SLOPE	adjacent slope angle
HS_HEIGHT	Head scarp height: change in elevation from bottom to top of head scarp
FAIL_DEPTH	Failure depth, estimated and/or calculated slope normal thickness of failure depth
FAN_HEIGHT	change in elevation from top to toe of fan
FAN_DEPTH	estimated and/or calculated fan depth
DEEP_SHAL	deep or shallow seated
HS_IS1	horizontal distance from head scarp to internal scarp no. 1
IS1_IS2	horizontal distance from internal scarp no. 1 to internal scarp no. 2
IS2_IS3	horizontal distance from internal scarp no. 2 to internal scarp no. 3
IS3_IS4	horizontal distance from internal scarp no. 3 to internal scarp no. 4
HD_AVE	Average horizontal distance between internal scarps: calculated average horizontal distance between scarps
DIRECT	direction of movement
AREA	area of landslide deposit
VOL	volume of landslide deposit

*Identification numbers (IDs) are sequential numbers (starting at 1 for the first mapped landslide) for each landslide mapped in each 7.5-minute quadrangle. The UNIQUE_ID is a concatenation of the QUADNAME and ID fields. UNIQUE_ID result in a unique code for every landslide mapped in the state of Oregon. An example of a unique ID is given below (in bold), with the corresponding reference info: **Portland_1** is the first landslide mapped within the Portland quadrangle.

Table 2. Simplified classification of landslides (Varnes, 1978).

Type of Movement	Type of Material					
	Rock		Debris		Soil	
Fall	**RF**	rock fall	**DF**	debris fall	**EF**	earth fall
Topple	**RT**	rock topple	**DT**	debris topple	**ET**	earth topple
Slide-rotational	**RS-R**	rock slide-rotational	**DS-R**	debris slide-rotational	**ES-R**	earth slide-rotational
Slide-translational	**RS-T**	rock slide-translational	**DS-T**	debris slide-translational	**ES-T**	earth slide-translational
Lateral spread	**RSP**	rock spread	**DSP**	debris spread	**ESP**	earth spread
Flow	**RFL**	rock flow	**DFL**	debris flow	**EFL**	earth flow
Complex	**C** complex or combinations of two or more types (for example, ES-R + EFL)					

Table 3. Confidence of landslide identification points and scale.

Landslide Feature	Points
Head scarp	0-10
Flanks	0-10
Toe	0-10
Internal scarps, sag ponds or closed depressions, compression ridges, etc.	0-10 *

Confidence	Total Points
High	> 30
Moderate	11–29
Low	≤ 10

*Applied only once so that total points do not exceed 40.

For debris-flow fans, the confidence scale should be used directly (e.g. low, moderate, high) based on the distinctness of the fan, as these types of landslide deposits do not have the landslide features associated with other landslides (Figure 15).

Some known landslides may not exhibit enough features (and thus enough points) to result in a moderate or high confidence. In these cases the scoring system should be overridden and a high confidence assigned.

5.2.2.4 Estimated age or time of landslide activity

Estimation of the age of a landslide can be very difficult. However, as age is often an important attribute for hazard assessments, an estimate should be attempted. In general, if a landslide has had recent activity (with the exception of channelized debris flows, rock falls, and topples), it will display topographic features as shown in Figure 16. In western Oregon, if there is no renewed movement, a landslide will begin to undergo geomorphic changes similar to that displayed in Figure 16. We recommend two age groups: historic (<150 years) and prehistoric (>150 years). The cutoff point of 150 years is used in Oregon, because the state was brought into the union as an official state in 1858.

- Historic or active (movement <150 years): The landslide appears to be currently moving or to have moved within historic time or historic data has identified the landslide as having moved in the last 150 years. Landslide features generally sharp and clear (Figure 16, example A).
- Prehistoric or ancient (movement >150 years): Landslide features are slightly to strongly eroded or covered with younger deposits. Features may be subdued and indistinct.(Figure 16, examples B and C).

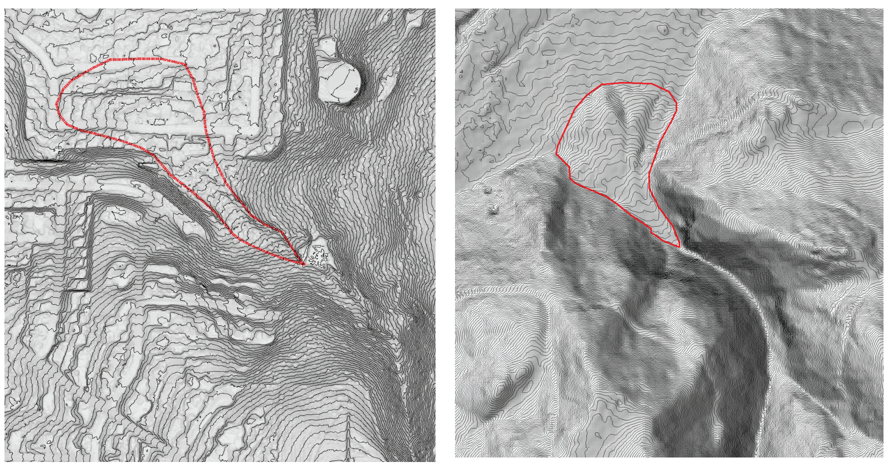
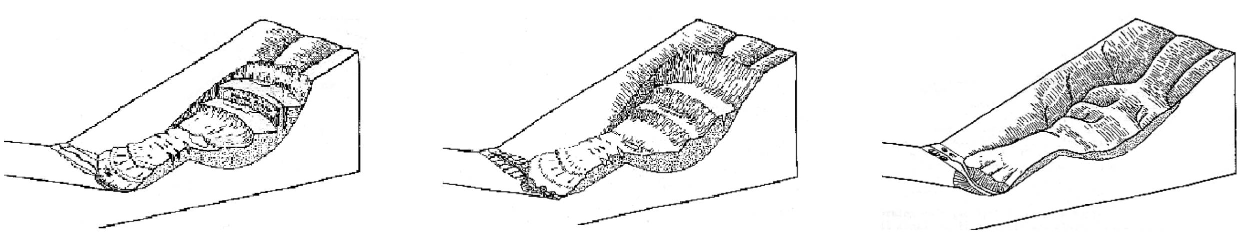


Figure 15. Examples of confidence for debris flow fans: (left) low and (right) high. The low-confidence example is in a highly developed area that has had earth movement, which can mask the original debris flow deposit.



A. Landslide featurs are sharply defined.

B. Landslide features are less defined. Slopewash and shallow mass movements modify sharp edges, but no drainage lines established.

C. Landslide features are very subtle. Drainage follows rifts and sags inside slide mass, internal blocks are dissected, material is eroded from slide mass.

Figure 16. Geomorphic changes in surface morphology of a landslide with time (McCalpin, 1974).

5.2.2.5 Known date of movement and landslide name

If there is a known date of last movement or successive movements, these dates should be recorded. Also, if the landslide has a common name (for example, the Washington Park Slide), the name should be entered into the tabular database.

6.2.2.6 Slope angle, head scarp, and fan depth measurements

To best estimate the slope angle of the ground prior to the landslide, the slope directly adjacent to the landslide should be measured on the DEM. This measurement will serve as an estimated prefailure slope angle (Figure 17). The slope angle will vary due to the accuracy of the DEM and variations in natural slope conditions, so the slope angle should be averaged. Slope angle should be recorded in degrees (0°–90°).

Head scarp vertical height should be measured. This measurement will be used to calculate an estimated slope normal thickness or depth of failure (Harp and others, 2006; Burns and others, 1998). Because the height of the head scarp will vary horizontally, the height should be measured at several locations along the head scarp and average height recorded (Figure 18).

In the case of a debris-flow fan, the estimated maximum depth should be measured on the DEM. This measurement will be used to calculate an estimated fan volume. In general, debris-flow fans tend to be shaped like a semi-circle in map view and fan volume is similar to half a cone. To calculate the volume of half a cone and thus to estimate the volume of the fan, the height of the cone (fan) is necessary. The height of the fan is the difference in elevation from the bottom to the top of the fan. An imaginary line should be drawn between

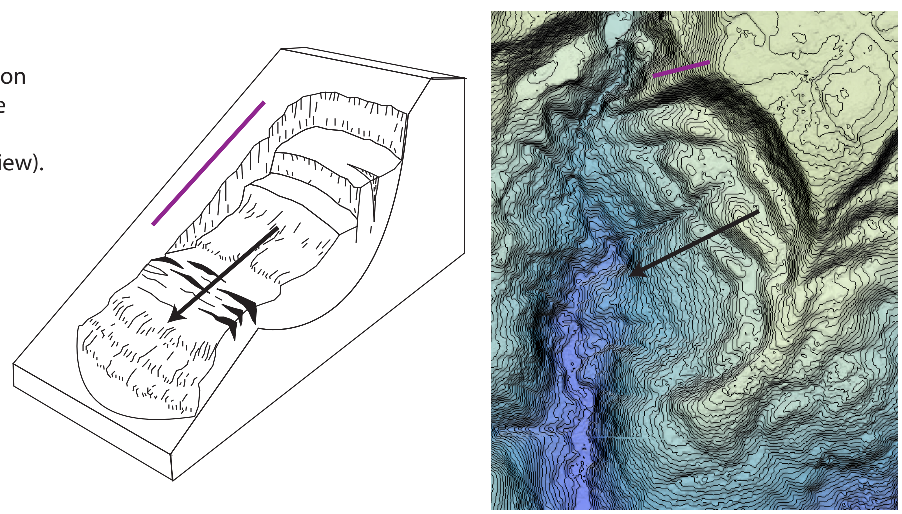


Figure 17. Example location to measure adjacent slope angle (purple line on the block diagram and map view).

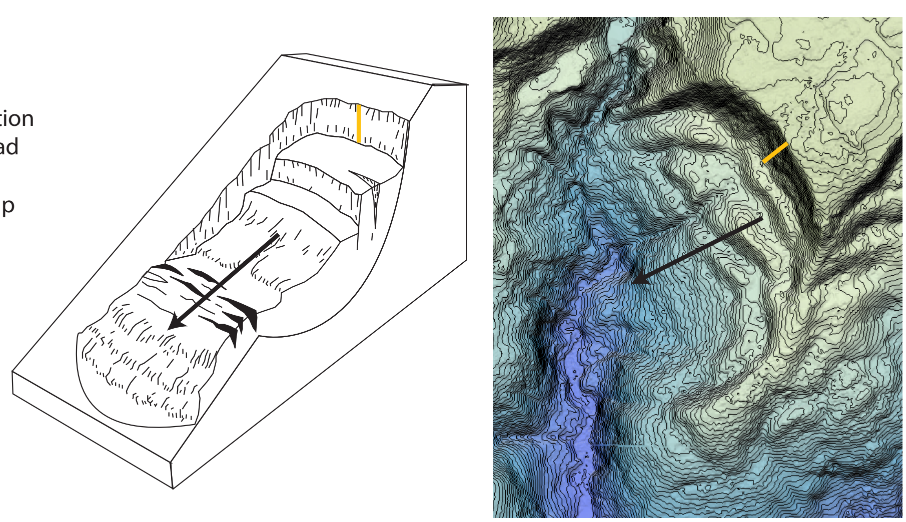


Figure 18. Example location to measure estimated head scarp height (yellow line on block diagram and map view).

the flat area where the fan is deposited and the base of the hills (dashed line in Figure 19). This imaginary line acts as the centerline of the cone (dividing the cone in half) and should be used to measure the highest elevation of the fan (yellow dot in Figure 19). The lowest elevation of the fan can then be measured perpendicular to the dashed line and along the lower edge of the mapped fan. The lower elevation should be subtracted from the higher elevation and the height recorded.

5.2.2.7 Classification of deep or shallow

After the slope angle and head scarp height have been measured, the estimated slope normal thickness or depth of failure should be calculated as shown in Figure 20.

This calculation is done to reduce the overestimation of thickness for relatively thin landslides on steep slopes. With an estimated slope normal thickness or depth of failure, the landslide can be classified as deep seated or shallow seated. This differentiation is necessary because different models are used to estimate regional stability or susceptibility for different landslide depths. There is no widely accepted boundary value between deep and shallow landslides. We selected 4.5 m (15 ft) as the boundary based on the combination of several factors and results from other studies.

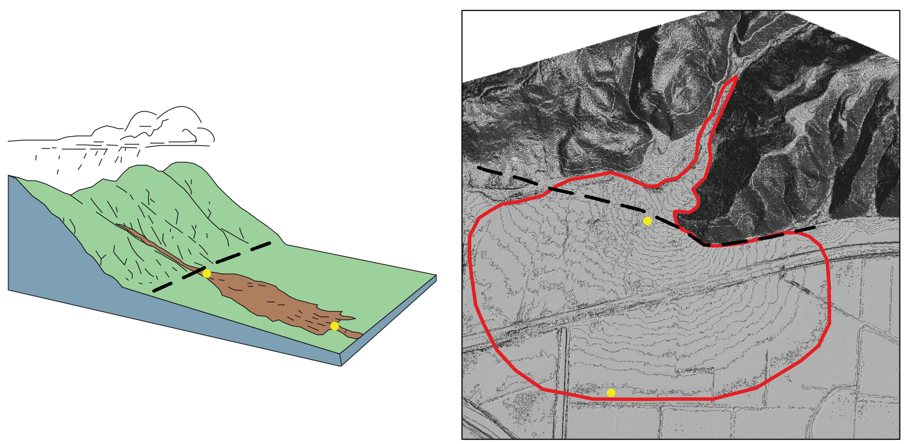


Figure 19. Example location to measure estimated maximum debris flow fan depth (elevation difference between two points – yellow dots).

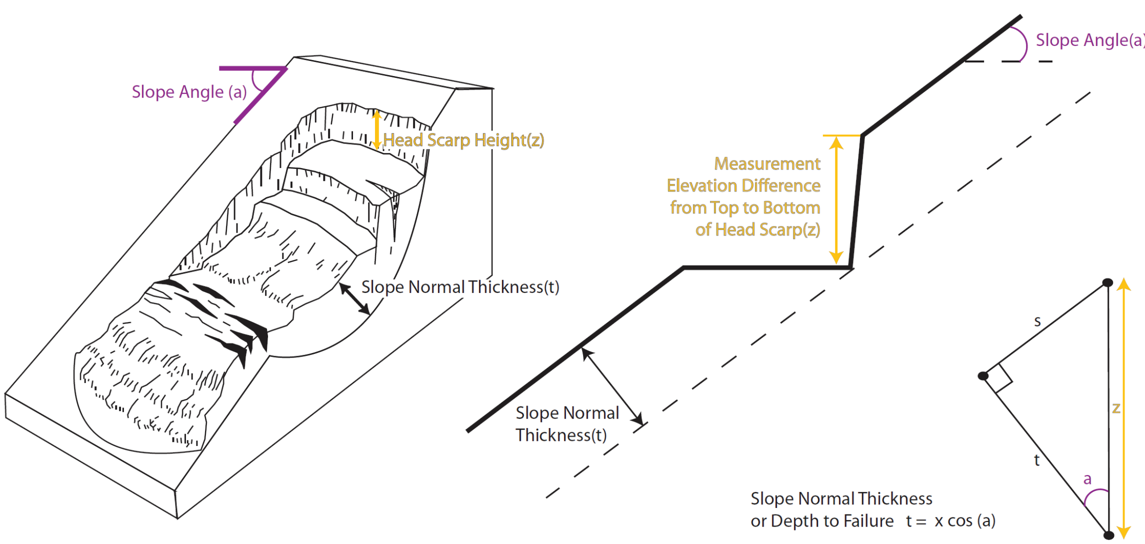


Figure 20. Calculation of estimated slope normal thickness or depth to failure.

Most geologists and engineers classify landslides as shallow or deep from the materials at the failure surface. If the basal failure surface is at or above the contact between surficial materials (colluvium, residual soil, etc.), then the landslide has traditionally been classified as "shallow." If the basal failure surface is below this contact (within the bedrock) then the landslide has been classified as "deep" (Figure 21). This is logical from a stability analysis and mitigation method perspective. However, this classification method results in a variable depth depending on how thick the surfical materials are at any given location.

Sidle and Ochiai (2006) note that shallow landslides are characteristically less than 2 m (6.5 ft) in depth and that deep landslides are generally greater than 5 m (16.5 ft) in depth. Burns (1998) found a bimodal distribution for depth to failure surfaces in a study area in Oregon City, Oregon. He concluded a cutoff value of 4.5 m (15 ft) was appropriate.

Excavations of up to 4.5 m (15 ft) have become routine (standard practice) in the construction industry. For example, an excavation for a typical residential house with a basement is generally between 3 m (10 ft) and 4.5 m (15 ft) deep. Because excavation and construction of structural entities such as retaining walls at this depth range has become standard practice, it is assumed that this practice would be used to potentially mitigate landslides or landslide areas with these depths.

On the other hand, areas that have deep-seated landslides or the potential for deep-seated landslides would likely require special types of mitigation that might include dewatering or construction of very large retaining structures.

On the basis of these factors and other studies, we selected a boundary value of 4.5 m (15 ft) between shallow-seated and deep-seated landslides.

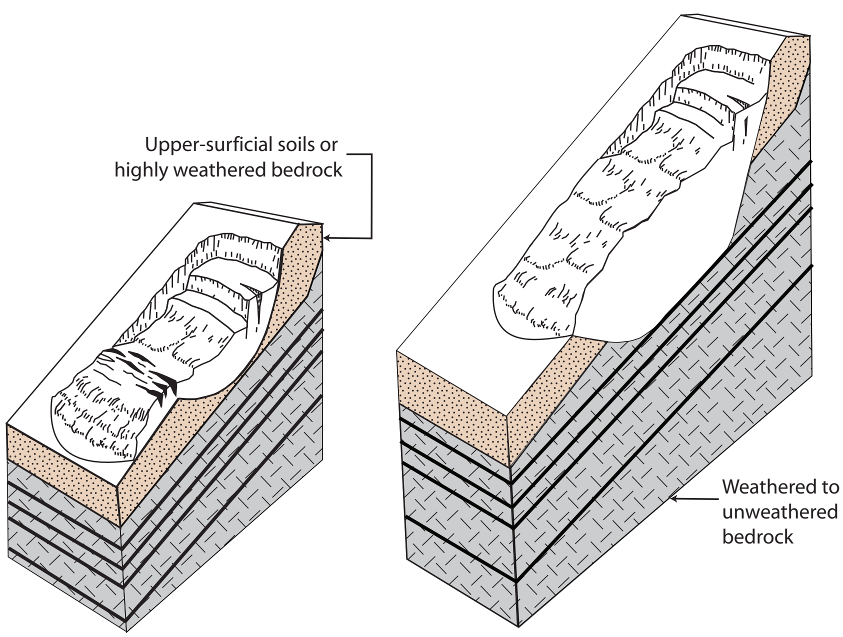


Figure 21. Example of shallow and deep-seated landslides.

5.2.2.8 Horizontal distance between scarps

The horizontal distance between all identified scarps, including the head scarp, should be measured on the DEM. This measurement may serve as an estimate of future retrogressive failure distance behind the uppermost head scarp (Figure 22). The horizontal distance should always be measured from the top of one scarp to the base of the upslope scarp (red line to red line in Figure 22), not from top of scarp to top of scarp.

After all the horizontal distances have been collected, an average distance should be calculated.

5.2.2.9 General movement direction and size

The last value that should be collected is the generalized movement direction. This value should be collected as an azimuth (0° to 360°) in increments of 22.5° so that a single number, in degrees, is recorded (Figure 23). The value should be recorded as one of the values shown in Figure 23. The direction should be measured from the approximate center of the uppermost head scarp to the approximate center of the toe.

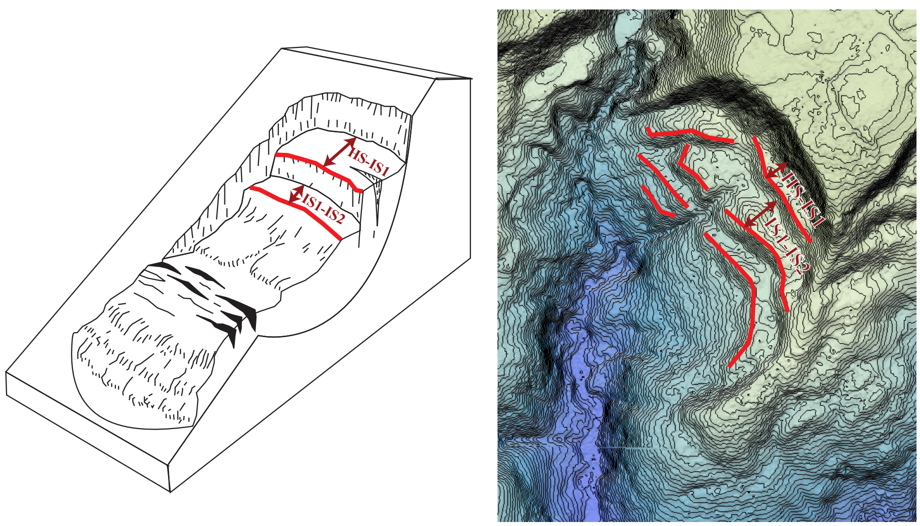


Figure 22. Example of horizontal distance measurements between two scarps (red lines). HS is the head scarp; IS1 and IS2 are internal scarps.

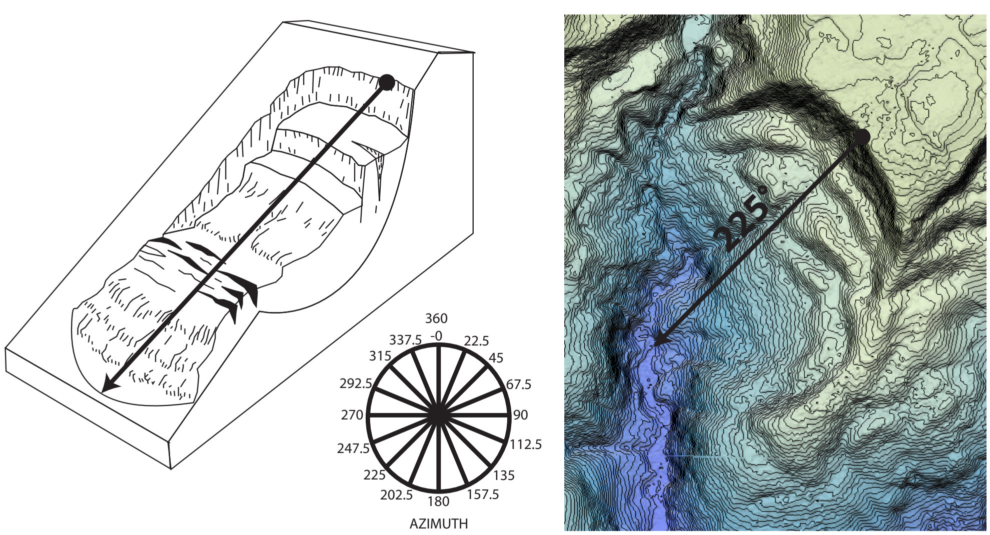


Figure 23. Example of measurement of direction of movement in azimuth (black line from ball to arrow).

5.2.2.10 Area and volume

The area of each landslide deposit should be estimated using a GIS program after the landslide deposit (polygon) has been drawn. Once the area has been found, the volume should be calculated by multiplying the area and depth. In the case of debris-flow fans, the area should be multiplied by one third of the estimated maximum depth, on the assumption that the volume of the fan is shaped like a half cone.

5.2.2.11 No data

In some cases, a mapper will not input data in the database, because there is not enough information to make a choice or the data are simply not available.

6.0 LANDSLIDE INVENTORY MAP TEMPLATE

A map template was developed as part of this protocol to display the data. The template was produced by building upon the Inventory Map Series developed by the California Geological Survey (Wiegers, 2006; Irvine and others, 2007) and an engineering geology map by Burns (1999) An example of the landslide protocol map template with the landslide inventory data from the northwest quarter of the Oregon City quadrangle is shown in Figure 24. The map template was developed to expedite publication of the data in a form that allows people without GIS software to quickly and easily view the data.

Because the "base map" on the map template is unique, a short description of how it was created is included here. The base consists of two layers: a hillshade image and an aerial photograph image. The hillshade image was created by transforming the original DEM using the "hillshade" tool in the Spatial Analysis extension of Environmental Systems Research Institute, Inc. (ESRI) ArcGIS™. The DEM was first multiplied by 5 times (vertical exaggeration) prior to the hillshade image creation to enhance slope areas. The settings in the "hillshade" tool included a sun angle at 315° and at 45° from the horizontal. A transparency of 40% was applied to this layer.

The aerial photograph image was created using 2005 statewide orthorectified images. The image was changed from RGB composite (multi-color) to a stretched color ramp from white to black (i.e., grayscale). A transparency of 45% was applied to this layer.

Finally, the two layers were grouped, and a brightness of 20% was applied. In the group, the hillshade image was placed on top of the orthophoto image.

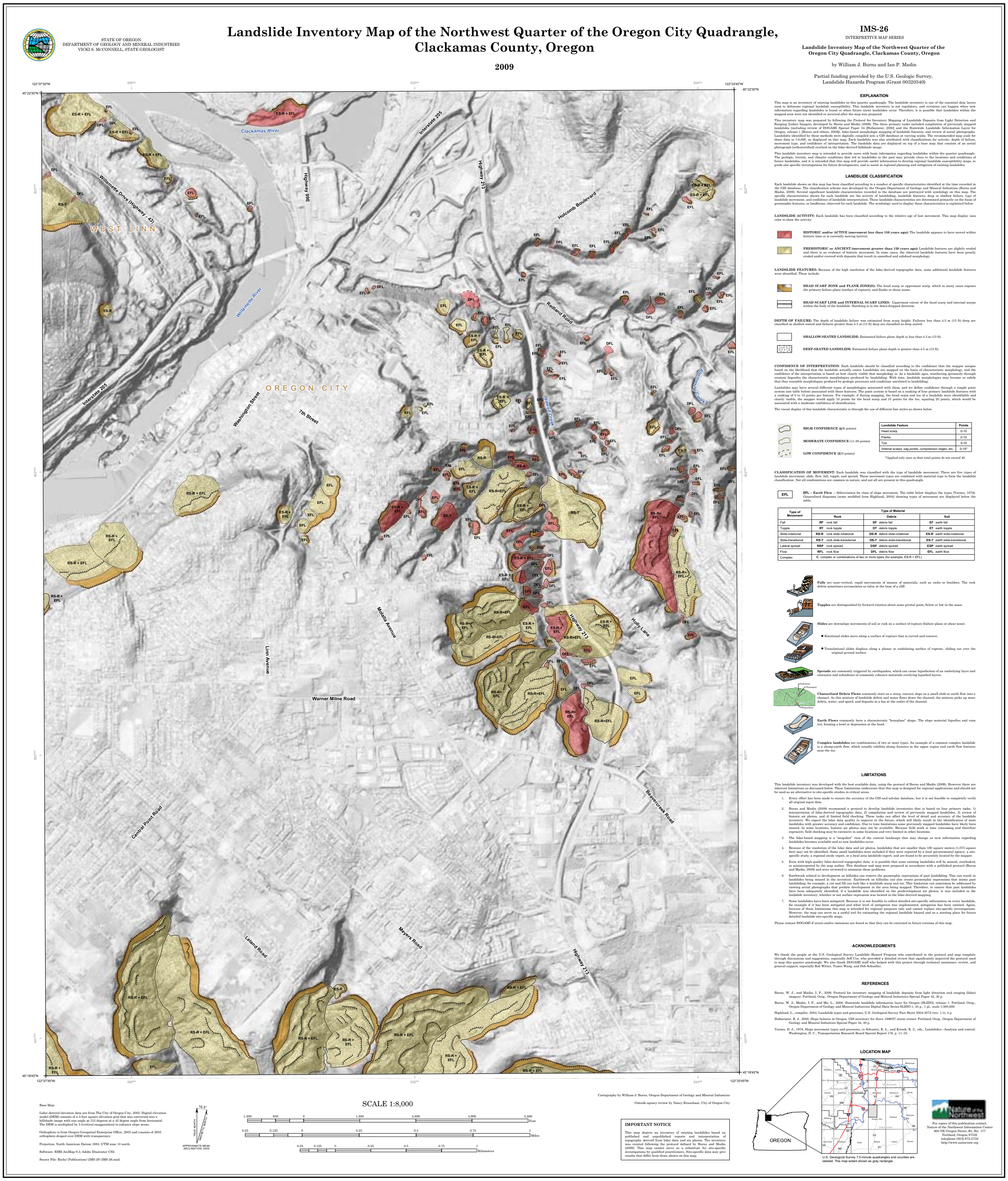


Figure 24. Example map displaying results based on the inventory mapping protocol described in this paper (DOGAMI Interpretive Map Series IMS-26, Burns and Madin, 2009).

7.0 LIMITATIONS OF MAPS PRODUCED USING THIS PROTOCOL

Several limitations are attached to the databases and maps created using this protocol. These limitations underscore that the databases and maps are designed for community-scale applications and should not be used as an alternative to site-specific studies in critical areas. The following list of limitations is included on the map template (see Figure 24 for example):

1. Every effort has been made to ensure the accuracy of the GIS and tabular database, but it is not feasible to completely verify all original input data.
2. Burns and Madin (2009) recommend a protocol to develop landslide inventories that is based on four primary tasks: 1) interpretation of lidar-derived topographic data, 2) compilation and review of previously mapped landslides, 3) review of historic air photos, and 4) limited field checking. These tasks can affect the level of detail and accuracy of the landslide inventory. We expect the lidar data quality to improve in the future, which will likely result in the identification of more landslides with greater accuracy and confidence. Due to time limitations some previously mapped landslides have likely been missed. In some locations, historic air photos may not be available. Because field work is time consuming and therefore expensive, field checking may be extensive in some locations and very limited in other locations.
3. The lidar-based mapping is a "snapshot" view of the current landscape that may change as new information regarding landslides becomes available and as new landslides occur.
4. Because of the resolution of the lidar data and air photos, landslides that are smaller than 100 square meters (1,075 square feet) may not be identified. Some small landslides were included if they were reported by a local governmental agency, a site-specific study, a regional study report, or a local area landslide expert, and are found to be accurately located by the mapper.
5. Even with high-quality lidar-derived topographic data, it is possible that some existing landslides will be missed, overlooked, or misinterpreted by the map author. This database and map were prepared in accordance with a published protocol (Burns and Madin, 2009) and were reviewed to minimize these problems.
6. Earthwork related to development on hillsides can remove the geomorphic expressions of past landsliding. This can result in landslides being missed in the inventory. Earthwork on hillsides can also create geomorphic expressions that mimic past landsliding; for example, a cut and fill can look like a landslide scarp and toe. This limitation can sometimes be addressed by viewing aerial photographs that predate development in the area being mapped. Therefore, to ensure that past landslides have been adequately identified, if a landslide was identified on the predevelopment air photos, it was included in the landslide inventory, whether or not surface expression was located in the lidar-derived mapping.
7. Some landslides have been mitigated. Because it is not feasible to collect detailed site-specific information on every landslide, for example if it has been mitigated and what level of mitigation was implemented, mitigation has been omitted. Again, because of these limitations this map is intended for regional purposes only and cannot replace site-specific investigations. However, the map can serve as a useful tool for estimating the regional landslide hazard and as a starting place for future detailed landslide site-specific maps.

8.0 POTENTIAL USES OF THE DATA AND MAPS PRODUCED USING THIS PROTOCOL

The primary purpose of this protocol is to explain how the mapping is done so that many maps can be created with consistent content and without generating a detailed, unique technical explanation for each map.

Landslide inventory databases and maps created using this protocol are intended to provide users with basic information regarding landslides within the quadrangle mapped. The geologic, terrain, and climatic conditions that led to slope failures in the past may provide clues to the locations and conditions of future slope failures.

Besides providing inventory data for SLIDO, spatial information in these landslide databases and maps should serve as useful tools for differentiating areas of higher and lower hazards. The data can also be used for applications such as those listed below. It is likely that individual communities will find unique and new applications to suit particular needs.

- Regional landslide susceptibility maps: The data gathered from inventory mapping using this protocol should be used to help create susceptibility maps. Susceptibility maps aid in estimating the potential for future landslides.
- Identifying vulnerable areas that may require special planning considerations,
- Estimating potential losses from specific landslide events,
- Emergency management applications: A potential use of the databases and maps is as an aid in emergency management activities such as developing and refining emergency response plans and estimating resource impacts from future landslide movement.
- Land-use planning: Common applications of landslide databases in land-use planning include input to comprehensive planning and development of hazard ordinances with attached zoning and regulations.
- Prioritizing mitigation measures to reduce future losses.

We reiterate that the databases and maps developed using this protocol are not definitive enough for site-specific evaluations; however, they are valuable for regional screening for landslides and selection of appropriate areas on which to focus further site-specific studies. The databases and maps produced using this protocol are particularly suitable for incorporation into state, county, and city development ordinances.

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11.0 APPENDIX A: GEODATABASE TABULAR FIELD DATA

Gray-shaded boxes are field names in the landslide geodatabase template. Unshaded boxes are allowed values per field. Variable type, field description, units (where applicable), and example data are also provided.

QUADNAME
Text; 7.5-minute quadrangle name.
Example: Oregon City

UNIQUE_ID
*Text; unique identification number: concatenation of QUADNAME_ID. **
Example: Oregon City_1

CONFIDENCE
Text; confidence of identification.
- High (≥30)
- Moderate (20-30)
- Low (≤20)

AGE
Text; estimated age.
- Historic (<150 years)
- Pre-Historic (>150 years)

DATE_MOVE
Text; date of last known movement or movements.
Examples: 10/6/1996, 2/12/1997

DEEP_SHAL
Text; deep or shallow seated; 4.5 m (15 ft) is the boundary value.
- Deep
- Shallow

NAME
Text; landslide name.
Example: Spady Landslide

GEOL
Text; geologic unit.
Example: Troutdale Formation

SLOPE
Float; adjacent slope angle, 0 to 90. Units: degrees. Example: 32

HS_HEIGHT
Float; change in elevation from bottom to top of head scarp. Units: feet. Example: 16

FAIL_DEPTH
Float; estimated calculated depth of failure. Units: feet. Example: 14

FAN_HEIGHT
Float; change in elevation from bottom to top of fan. Units: feet. Example: 35

TYPE_MOVE *Text; type of movement.*	MOVE_CLASS *Text; movement classification.*	MOVE_CODE *Text; movement classification code.*
Slide	Debris Slide - Rotational	DS-R
	Debris Slide - Translational	DS-T
	Earth Slide - Rotational	ES-R
	Earth Slide - Translational	ES-T
	Rock Slide - Rotational	RS-R
	Rock Slide - Translational	RS-T
Flow	Debris Flow	DFL
	Earth Flow	EFL
	Rock Flow	RFL
Spread	Debris Spread	DSP
	Rock Spread	RSP
	Rock Spread	RSP
Fall	Debris Fall	DF
	Rock Fall	RF
	Rock Fall	RF
Topple	Debris Topple	DT
	Earth Topple	ET
	Rock Topple	RT
Complex	Complex	C
	Complex Earth Slide - Rotational & Earth Flow	ES-R>EFL

FAN_DEPTH
Float; estimated calculated fan depth. Units: feet. Example: 33

HS_IS1
Float; horizontal distance from head scarp (HS) to internal scarp no. 1 (IS1). Units: feet. Example: 5

IS1_IS2
Float; horizontal distance from internal scarp no. 1 (IS1) to internal scarp no. 2 (IS2). Units: feet. Example: 5

IS2_IS3
Float; horizontal distance from internal scarp no. 2 (IS2) to internal scarp no. 3 (IS3). Units: feet. Example: 5

IS3_IS4
Float; horizontal distance from internal scarp no. 3 (IS3) to internal scarp no. 4 (IS4). Units: feet. Example: 5

HD_AVE
Float; calculated average horizontal distance between scarps. Units: feet. Example: 5

DIRECT
Float; direction of movement, in increments of 22.5. Units: degrees.
- 0
- 22.5
- 45
- 76.5
- 90
- 112.5
- 135
- 157.5
- 180
- 202.5
- 225
- 247.5
- 270
- 292.5
- 315
- 337.5
- 360

AREA
Float; size of landslide deposit. Units: square feet. Example: 500

VOL
Float; volume of landslide deposit. Units: cubic feet. Example: 7000

* Identification numbers (IDs) are sequential numbers (starting at 1 for the first mapped landslide) for each landslide mapped in each 7.5-minute quadrangle.

12.0 APPENDIX B: GUIDELINES FOR WORKING WITH THE LANDSLIDE GEODATABASE TEMPLATE

Note: An ArcInfo or ArcEditor license is necessary to edit a geodatabase that contains relationship classes or topologies. If you do not have access to these licenses, use the ArcView license level geodatabase provided.

12.1 EDITING GUIDELINES

- Feature classes must always be named Deposits, Scarp_Flanks, Scarps, and Photos. Use the empty feature classes provided you in the geodatabase. These feature classes are already named, and they have the correct fields and domains built in.
- Relationship classes exist between these four feature classes. The relationship classes assume that the Deposits features are the parent features. During editing, if a Deposits feature is deleted, any Scarps, Flanks, or Photos features will also be deleted, given the Unique_ID that connects the features is present in all related features.
- Domains are established to decrease the amount attribute entry you need to do and to ensure that typographic errors do not sneak into the data. These domains appear via dropdown menus in the Attributes dialog box or in the Attribute table.

12.2 WORKFLOW

- Because Deposits are considered the parent feature to which all other features are related, it is recommended that your workflow be as follows: draw and attribute the Deposits feature, then draw its associated Scarp_Flanks, then create Scarps and Photos features from the geometry of these features.
- Because the Scarps lines should be exactly coincident with Scarp_Flanks edges, these must match vertex for vertex. A simple way to do this is to draw the Scarp_Flanks polygon, then copy and paste it into Scarps. You can then clip the line to the extent of the Scarp and you will have an identical feature.

12.3 TIPS AND TRICKS FOR EDITING

- Change your sticky-move tolerance to something large, like 50 (Editor > Options > General tab).
- Set your Snapping tolerance to some number between about 7 and 12 (Editor > Options > General tab).
- Auto-Complete will fill in the areas adjacent to existing polygons if you snap to vertex on both sides of the area in which you want a new polygon (Editor toolbar > Task dropdown menu).
- Other options under Topology Tasks include Reshape Edge and Modify Edge. These tools will simultaneously edit features that have a shared edge. They are accessible through a geodatabase topology but are also accessible through a Map Topology, for which you don't need an ArcInfo license. (See Geodatabase Topologies section, Figures B1 and B2.)
    - To build a map topology, choose Editing> Start. Turn on the Topology toolbar and click the Map Topology button (just to the right of the Map Layers dropdown menu). Choose the layers you want to participate in the topology and click OK. The map topology only lasts for your edit session; you must build a new one each time you start editing.
- Other methods for editing that will ensure coincident features include the Trace tool (same location as the sketch tool, but the bottom right choice).
- **Be careful** of Clip! It will clip through all visible layers you are currently editing. Because of this, I will frequently keep a junk clip feature class handy into which I can copy and paste features to do a quick clip until they are topologically coincident — making sure, of course, that I have turned off all other layers! — and then copy them back into my main feature class. I then can use the Attribute Transfer Tool (Spatial Adjustment toolbar) to copy all the attributes from the old feature to the newly-clipped feature (see below).

12.4 ATTRIBUTES

- The key attribute field for these feature classes is the Unique_ID field. This is a string field that is the Quad name concatenated with a unique ID number (1–*n*, where n is the last feature you created). This field is what the relationship classes and the error-checking tools below rely on, and it is very important that for the Deposits feature class, the Unique_ID has **no duplicates**.
- If you have ArcInfo license, you can use the Frequency tool to check to see if any value of Unique_ID has more than one occurrence (Analysis Tools > Statistics). This is similar to a pivot table in Excel, so you could export the attribute table as a .dbf file and open it in Excel to check for duplicates. Access also provides a handy wizard to check for duplicates. **Be careful** when accessing your geodatabase tables from Microsoft Access.
- During editing, you can sort in ascending or descending order in the Attribute table to find out what your next-highest unique ID number should be. Because this is an alphanumeric field, the format for the Unique_ID should be as follows:

  [Quad Name]_001
  [Quad Name]_011
  [Quad Name]_111
- For this work, all attributes are carried in Deposits, and smaller subsets of the same attributes are carried in the Photo, Scarps, and Scarp_Flanks feature classes. After all your features are drawn, and your Deposits feature is fully attributed, you can use the Attribute Transfer Mapping tool on the Spatial Adjustment toolbar.
  - Click Spatial Adjustment and Attribute Transfer Mapping. A dialog box appears. Specify your From layer—which will always be Deposits—and your To layer—Scarp_Flanks, Scarps, or Photo. Auto-Match will automatically find the fields the two layers have in common. Uncheck the Transfer Geometry option. Click Okay. In ArcMap your cursor will now be a round circle. Click in a From feature and then click a target To feature. For each target feature, you must again click in a From feature. You can have only one From layer and one To layer specified at a time.

12.5 CHECKING YOUR WORK

- If you have ArcInfo or ArcEditor, you can create a geodatabase topology that will establish rules between feature classes. See ArcMap Help for more information.
- Two additional tools can help check your work, once you are entirely finished editing: Find Unmatched Features and Unjoin Layers. These simple models can be run in ArcGIS. Add the provided toolbox to ArcMap (right-click in the white area of your Toolbox Window and choose Add) and expand to see the two models.
  - Find Unmatched Features locates Scarp_Flanks, Scarps, or Photo features with Unique_IDs that do not have a matching Unique_ID in Deposits. These will be selected on your screen after you run the model. You may scroll to all selected items in your data view to check them before deleting them, or you may export the selected items as a temporary shapefile or feature class so that you have a guide for which features to check.
  - When you click on the Find Unmatched Features model, a dialog box appears with one drop-down option. Select Scarps, Photos, or Scarp_Flanks, as these are the layers you are comparing to Deposits.
  - You can run this model three times (one for each feature class), and the features will remain selected in all three feature classes. However, you cannot run it again for the same feature class until you run the second model, Unjoin Layers.
  - For your selections to appear, you must turn the layer off and on.
  - For your selections to disappear after you have run Unjoin Layers, you must scroll so that the selected features go out of the edges of the data frame.

12.6 GEODATABASE TOPOLOGIES

- It is an optional step to add a topology to your Feature Dataset. This is useful for checking your work for various mismatches and editing errors in the data, as well as easily repairing some topology errors. Some sample topology rules and editing tasks are described below.
    - The topology can be modified with ArcCatalog to fit certain needs, as the rules already set for you are not true all the time. These rules, however, will help to find certain errors in your data. If a feature is marked as a topology error and it is in fact not, you can mark it as an exception with the Fix Topology Error tool on the Topology toolbar. (For example, sometimes Deposits features really do overlap each other.)
    - Current topology rules:
        - Deposits must not overlap self
        - Deposits must not overlap Scarp_Flanks
        - Scarps must be covered by boundary of Scarp_Flanks
- An added benefit of a topology is the topology editing tools. Using the Topology Edit tool on the Topology toolbar, you can click an edge or a node (see Figures B1 and B2) and it will turn pink. You can then selected the Topology edit tasks instead of the standard ones and reshape or move several features at one time.

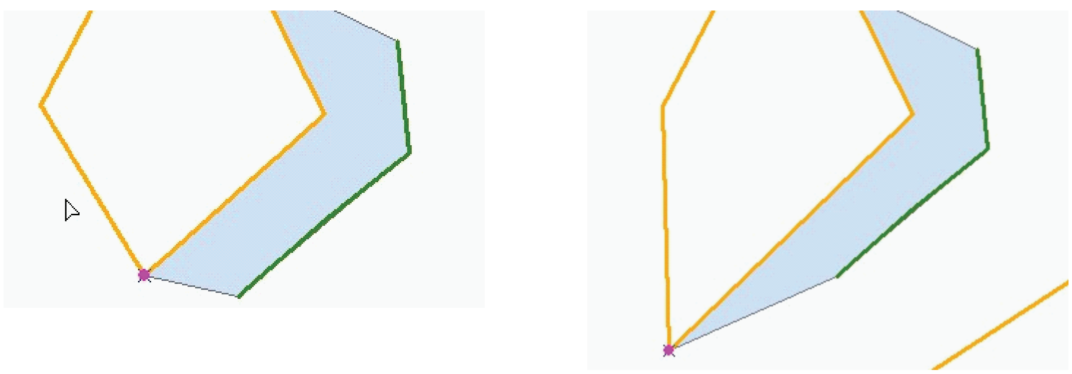

Figure B1. Edit all features connected to the node. Dragging the node changes the shapes of both polygons.

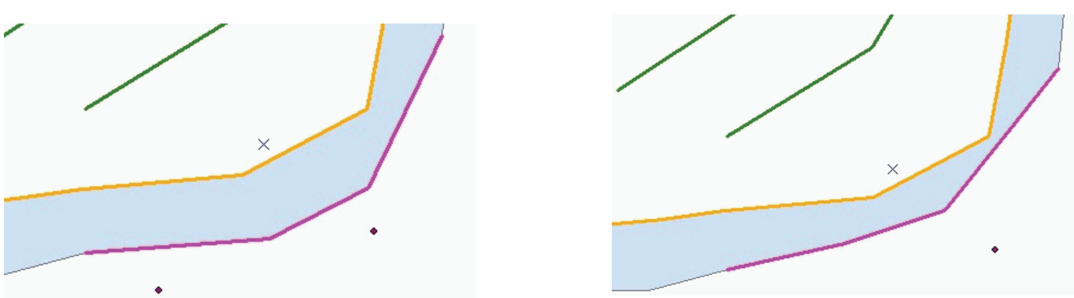

Figure B2. Edit the shape of all features under edge (scarp is highlighted pink). Deleting a node and dragging the line changes the shapes of both the line and the polygon.