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LIDAR DATA AND LANDSLIDE INVENTORY MAPS OF THE NORTH FORK SIUSLAW RIVER AND BIG ELK CREEK WATERSHEDS, LANE, LINCOLN, AND BENTON COUNTIES, OREGON

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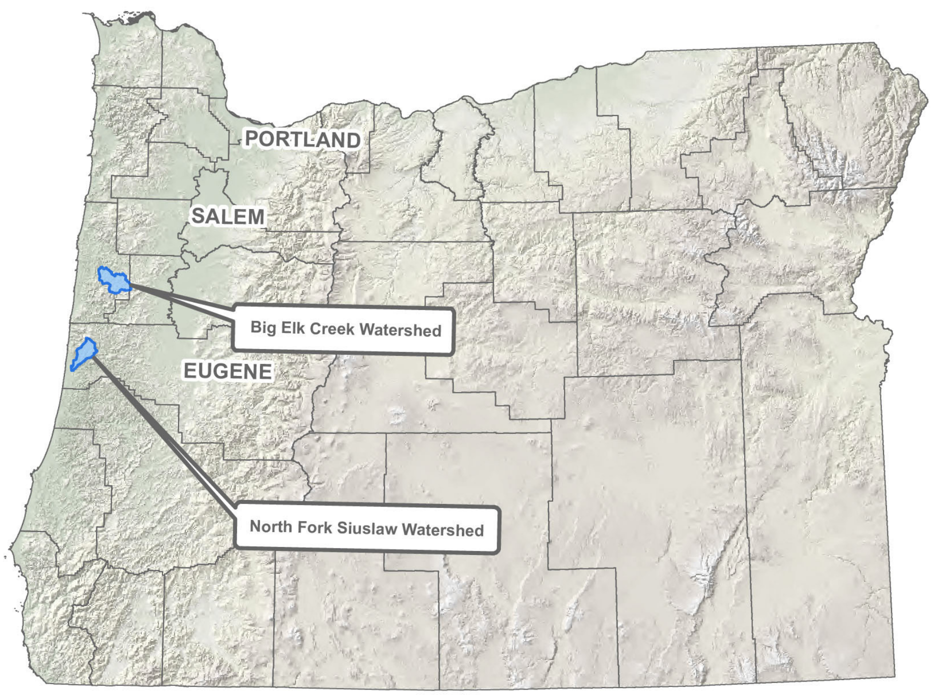

2012

NOTICE

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B: Lidar Remote Sensing Data Collection Report for the Central Coast Study Area, January 2012, by Watershed Sciences, Inc.

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1.0 EXECUTIVE SUMMARY

In August 2011 the Oregon Department of Geology and Mineral Industries (DOGAMI) contracted with the United States Environmental Protection Agency (US EPA) (Order EP-11-7-000174) to collect lidar (light detection and ranging) data for seven watersheds in the Oregon Coast Range Mountains and to perform regional landslide inventory mapping of two of these watersheds.

The purpose of this study was to assist US EPA and the Oregon Department of Environmental Quality (DEQ) in understanding potential landslide sources and to improve ability of these agencies to identify other potential sources of stream sedimentation and warming by using high-resolution lidar data. Lidar collection and landslide mapping were undertaken because US EPA and DEQ are concerned about excessive sedimentation, turbid waters, and stream warming in watersheds in Coast Range. Some common sources for sedimentation and stream warming include landslides, unmaintained roads, lack of vegetation, and degraded stream banks. One major obstacle to correctly assigning sources is the lack of accurate topographic data and landslide maps. Recent studies have shown that the use of light detection and ranging (lidar) data to map landslides greatly improves the accuracy of the maps.

Two main tasks were required to accomplish the purpose: 1) lidar data acquisition, processing, quality control review, and data/report delivery and 2) landslide mapping and data delivery.

- Task 1 included acquiring new lidar data and combining these data with existing lidar data to cover the seven watersheds. Examples of methods that can be used to identify both landslide and nonlandslide sources of sediment and stream warming are described in this report.
- Task 2 included creating a landslide inventory geodatabase following the protocol of Burns and Madin (2009) (see Appendix A of this report) and providing map imagery. The data in this inventory are much more complete than those in previous inventories. For example, previous inventories, which include seven studies covering the North Fork Siuslaw and Big Elk Creek watersheds, locate a total of 261 landslide deposits, whereas the current study locates 2,840 landslide deposits in these same two watersheds.

2.0 BACKGROUND

Excessive sedimentation, turbid waters, and stream warming are of concern in watersheds in the Coast Range. In order to reduce these affects, identifying and minimizing anthropogenic sources that contribute to excessive sediment and stream warming is a high priority of the Unites States Environmental Protection Agency (US EPA). Some common sources for sedimentation and stream warming include landslides, unmaintained roads, lack of vegetation, and degraded stream banks. One of the major obstacles to correctly identifying these sources is the lack of accurate topographic data and landslide maps. Recent studies have shown that the use of lidar (light detection and ranging) data to map landslides greatly improves mapping accuracy (Burns, 2007).

Landslides, one source of sedimentation in watersheds, are among the most widespread, chronic, and damaging natural hazards in Oregon. It is recognized that large extents of the Oregon Coast Range Mountains are susceptible to landslides. During the severe storms that affected the state in 1996-1997, thousands of landslides were documented in the Coast Range (Figure 1). Most of these landslides were documented as part of regional studies or because they were located along roads and/or were easily accessible.

The geology in the North Fork Siuslaw watershed is primarily Tertiary age interbedded sandstone and siltstone of the Tyee Formation. Most of the Tyee Formation dips toward the southwest at approximately 10 degrees. In the northwestern portion of the watershed, the Tyee Formation is overlain by rocks of Tertiary Yachats Basalt formation, mostly basaltic volcaniclastic rocks. Tertiary intrusive rocks are also present throughout the watershed, and Quaternary alluvium occurs along major rivers (Schlicker and others, 1974; Ma and others, 2009).

The geology in the Big Elk Creek watershed is similar to that in the North Fork Siuslaw. The primary unit is the Tyee Formation, except here it generally dips toward the north and/or west. Tertiary intrusive rocks are also present, and Quaternary alluvium occurs along major rivers (Schlicker and others, 1973; Ma and others, 2009).

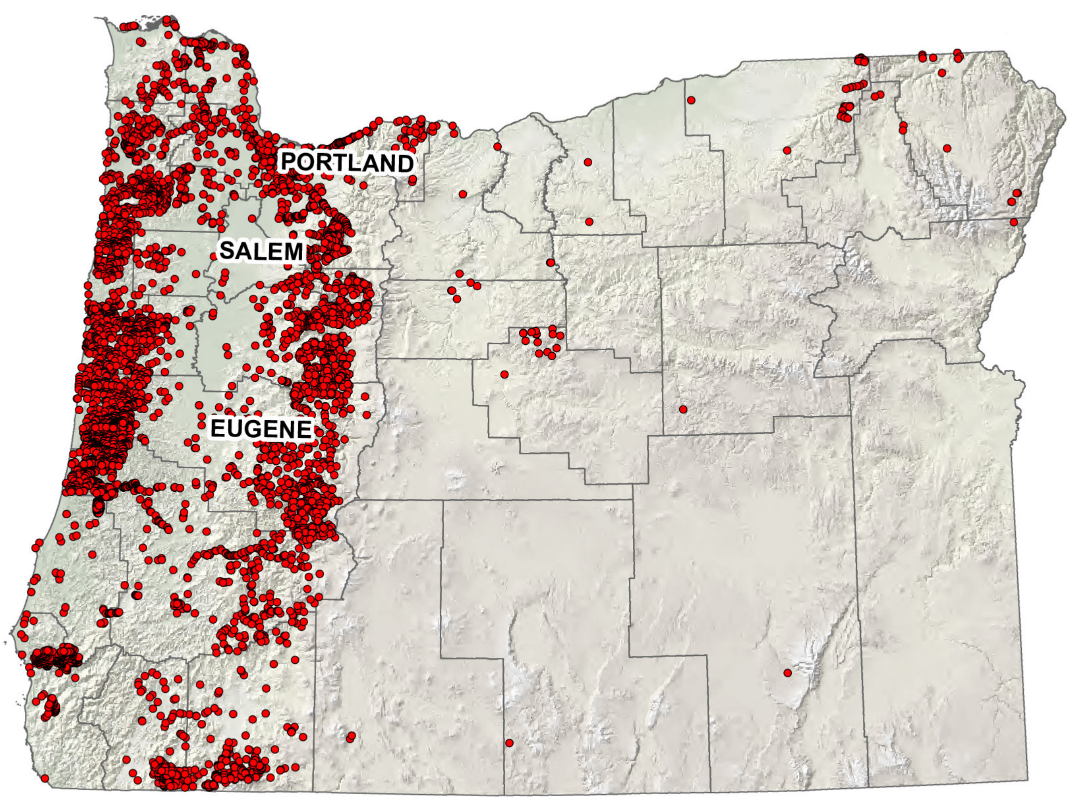


Figure 1. Landslides locations (red dots) from the 1996-1997 severe storms (data from Burns and others, 2011).

3.0 PURPOSE AND SCOPE

The purpose of this study was to assist the US EPA and Oregon Department of Environmental Quality (DEQ) in understanding potential landslide sources and to improve the ability of these agencies to identify other potential sources of stream sedimentation and warming by using high-resolution lidar data.

Two main tasks were undertaken to accomplish the purpose: 1) lidar data acquisition, processing, and data/report delivery and 2) landslide mapping and data delivery. The project started in August 2011 and was finished in December 2012. Table 1 includes the watersheds and the primary tasks associated with each watershed (Figure 2). This report focuses on the North Fork Siuslaw and Big Elk Creek watersheds.

Table 1. Project areas and tasks.

Watershed Project Area	Hydrologic Unit Code	Project Area (mi^2)	Lidar Data Collected?	Landslide Inventory Mapped?
Lower Siletz River	1710020407	44.5	yes	no
Rock Creek	1710020406	43.1	yes	no
Middle/Upper Siletz River	1710020405/ 1710020404	54.9	yes	no
Drift Creek	1710020503	61.8	yes	no
North Fork Siuslaw River	1710020607	59.6	yes	yes
Big Elk Creek	1710020402	51.9	yes (west 1/2)	yes (entire watershed)
South Fork Trask	1710020304	28.5	yes	no

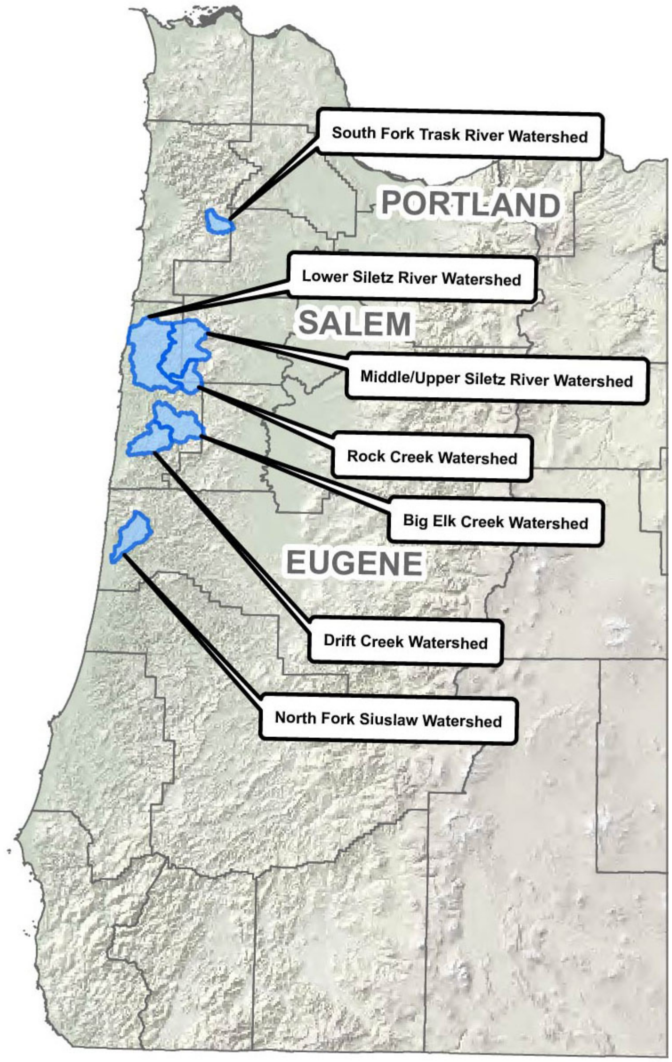


Figure 2. The seven watersheds (outlined in blue) for which lidar data were collected in this study: South Fork Trask River, Lower Siletz River, Middle/Upper Siletz River, Rock Creek, Big Elk Creek Drift Creek, and North Fork Siuslaw River.

4.0 METHODS

The two primary tasks, lidar data acquisition and landslide mapping, were completed following the methods described or referenced below.

4.1 Lidar data acquisition, processing, and quality assurance

The lidar data were collected using Leica ALS 50, ALS 60, and ALS 70 sensors mounted in aircraft flown at 900 and 1,400 m above ground level. Scanners collected over 100,000 XYZ measurements per second to create a three-dimensional "point cloud." Lidar is unique in that it is able to "see through" vegetation and thus allow measurements of bare ground as well as vegetation height in a single laser pulse. Specialized computer software was used to extract measurements of the bare ground from the overall point cloud so that models of bare earth could be created. Digital elevation models (DEMs) were created by interpolating point elevation values to uniformly gridded rasters. A report from Watershed Sciences, Inc., the lidar data collection vendor, is included as Appendix B.

After the data were collected, DOGAMI staff performed extensive quality assurance including field and computer based analysis. A quality assurance report is included as Appendix C.

The gridded rasters (first return and bare earth) were then processed using GIS software to create shaded relief and other visually understandable images. Such imagery can assist experienced users in mapping landslides and in identifying other potential sediment and stream warming sources (Figures 8 and 11; Plates 1 and 2).

4.2 Landslide inventory mapping

The use of lidar-derived bare earth digital elevation models (DEM) is the key to landslide mapping performed in this study. Lidar-derived imagery, together with other datasets such as aerial photographs, provides very accurate surface geomorphology, which can be used to identify features associated with landslides—such as concave slope depressions, vertical or steep scarps, shear zones located along the flanks of a landslide, and shortening features of landslides such as toes. The ability to recognize these features on a DEM means landslides can be identified with a high level of certainty and mapped accurately.

In preparation for lidar-based landslide mapping in the North Fork Siuslaw and Big Elk Creek watersheds, several existing landslide and geologic reports and maps were reviewed. If the landslide data were well located, the data were included in the new geodatabase. These reports include:

1. The Statewide Landslide Information Database for Oregon, release 2 (SLIDO-2; Burns and others, 2011). This dataset includes landslides that occurred during the severe storms of 1996-1997. Some of these data were omitted from the geodatabase because the points were not accurately located, the landslide debris had been removed, or the landslide was simply too small or unmappable on the lidar imagery. However, these point data are easily accessible in GIS or on the SLIDO-2 web map viewer at http://www.oregongeology.org/sub/slido/index.htm.
2. The latest geologic maps of the area including Oregon Geologic Data Compilation, release 5 (OGDC-5; Ma and others, 2009) and environmental geology of coastal Lane County, Oregon (Schlicker and others, 1974).
3. GIS overview map of potential rapidly moving landslide hazards in western Oregon (Hofmeister and others, 2002).
4. Mass movement dynamics, geomorphology and their relationship to geology in the North Fork Siuslaw River drainage basin (Graham, 1985).

After review of previous regional studies, landslide inventories of North Fork Siuslaw and Big Elk Creek watersheds were mapped following the protocol of Burns and Madin (2009); this protocol is included as Appendix A. The recommended geodatabase map scale for the landslide data is 1:8,000. A geodatabase for each watershed contains geographic information system (GIS) datasets for deposit polygons, head scarp and flank polygons, and internal scarp lines. Each landslide is also attributed with 29 fields including activity, type of movement, confidence of interpretation, age, slope, estimated depth of failure, area, and volume, according to the protocol of Burns and Madin (2009). Mapping was not checked in the field, although field checking is recommended by Burns and Madin (2009).

To supplement lidar-based mapping, orthophoto series (1995, 2000, 2005, and 2009) were examined to add more historic landslides and to add dates of movement to some landslides mapped from lidar.

Thematic maps using the lidar-derived hillshade images were then prepared (Figures 8 and 11; Plates 1 and 2).

5.0 RESULTS AND DISCUSSION

5.1 Lidar data

New lidar data were acquired and combined with existing lidar data from an earlier study; newly acquired data are available from the Nature of the Northwest Information Center as Lidar Data Quadrangle (LDQ) series publications. It was discovered that the bare-earth raster grids for the eastern half of the Big Elk Creek watershed (data from the earlier study) had been poorly processed. This resulted in a poor quality DEM and thus poor derived imagery. The existing data were reprocessed, and the newly processed data were used for landslide mapping. The reprocessed lidar data were provided to US EPA and DEQ.

Although lidar data were collected at ≥8 points per 10.8 square feet (1 square meter), which is nearly one point per square foot, in some places the distance between *ground* points was measured to be approximately 50 feet or more (Appendix B); the sparsely spaced ground points is likely due to the dense vegetation in these areas. The paucity of points resulted in some long linear interpolations between ground points to create the bare-earth DEM (Figure 3). Because lidar-based landslide mapping is highly dependent on the resolution of bare-earth DEM, poor resolution DEMs can cause inaccuracies.

Each map plate (Plates 1 and 2) includes a small physiographic map showing mapped landslides as well as alternative views of three locations on the map (Figures 4, 5, and 6) that highlight ways of displaying lidar data such that potential sediment and stream warming sources other than landslides can be identified.

The physiographic map highlights the ground morphology and elevation distribution within each basin. For example, on Plate 1 (Siuslaw) the elevation change in the lower third of the watershed is relatively small (roughly 0–800 ft) compared to that in the upper two thirds, which has elevation changes from roughly 0 to 2,300 ft.

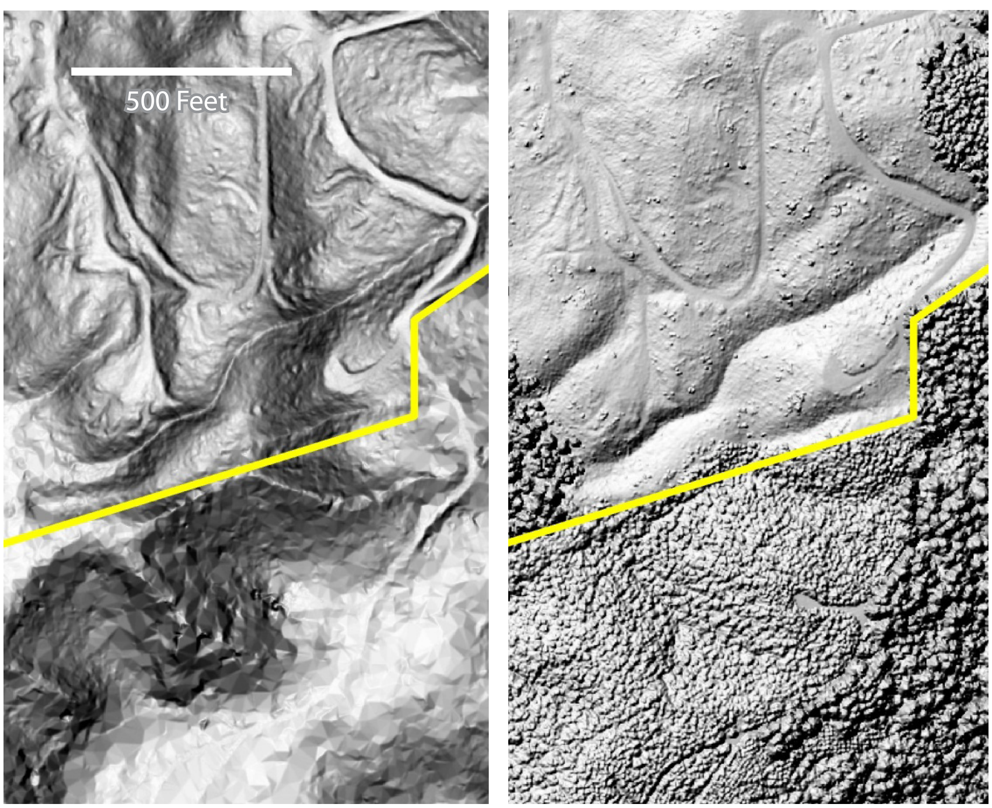


Figure 3. (left) Example of lidar-derived bare-earth image of an area within the North Fork Siuslaw watershed that contains both closely spaced ground points (north side of the yellow line) and sparsely spaced ground points (south of the yellow line). (right) First-return image of the same area shows that the likely cause of the sparsely spaced ground points is dense vegetation in this area.

The intensity data, which are part of the lidar dataset, are rarely used but can be very helpful especially in areas with little or no elevation changes or in combination with other datasets. View C (Figure 4, Plate 1 and Plate 2) is an example of an intensity image displaying variations in surface reflectivity. Intensity data are reflectance values acquired by the lidar laser system on the basis of the reflectivity of the target area; darker surfaces absorb more of the laser's light, while bright surfaces reflect more. Some features that can be clearly seen include impervious surfaces like roads, especially in flat areas with little or no elevation change and land use like plowed agricultural fields versus unplowed grazing fields.

Figure 4. Example lidar-derived map displaying intensity data where white is the more reflective surface and black is the less reflective surface. Also note that the plowed agricultural field (right) and unplowed (grazing) field (left) can easily be distinguished.

Because there are two elevation raster datasets (first return and bare earth), the bare-earth DEM can be subtracted from the first-return DEM to produce a height raster that shows the height of vegetation and structures above the ground surface. View B (Figure 5; Plate 1, and Plate 2) is an example of a method to display the height raster by assigned colors based on the height values. The height raster can be used to locate assets such as stands of trees or other types of vegetation and structures such as residential homes or other structures and shows enough detail to differentiate between cars and other man-made structures.

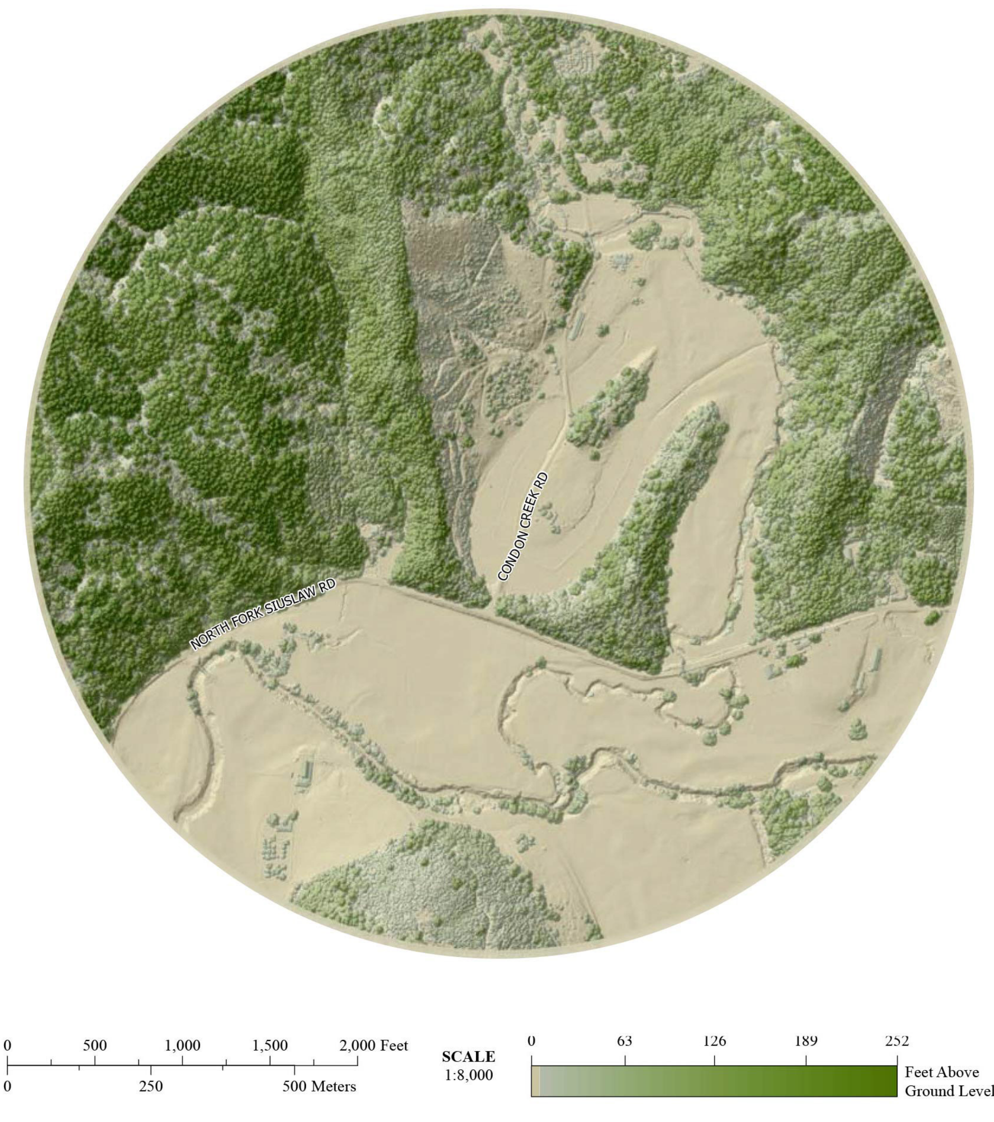


Figure 5. Example lidar-derived map displaying height data where dark green indicates taller features and light green indicates shorter features.

The bare-earth DEM can be used to create derivative datasets such as a slope map of the ground. View A (Figure 6, Plate 1 and Plate 2) is an example of a method to display the steepness of slopes. The slope image, besides differentiate steep slope areas from flat areas, can assist in identifying very slight changes in slope, such as those shown in the debris flow fan deposit areas outlined in black in Figure 6. In Figure 6, the debris flow fans have slopes of roughly 5–10 degrees, whereas the nearly flat alluvial deposits along the main river channel have slopes of roughly 0–5 degrees.

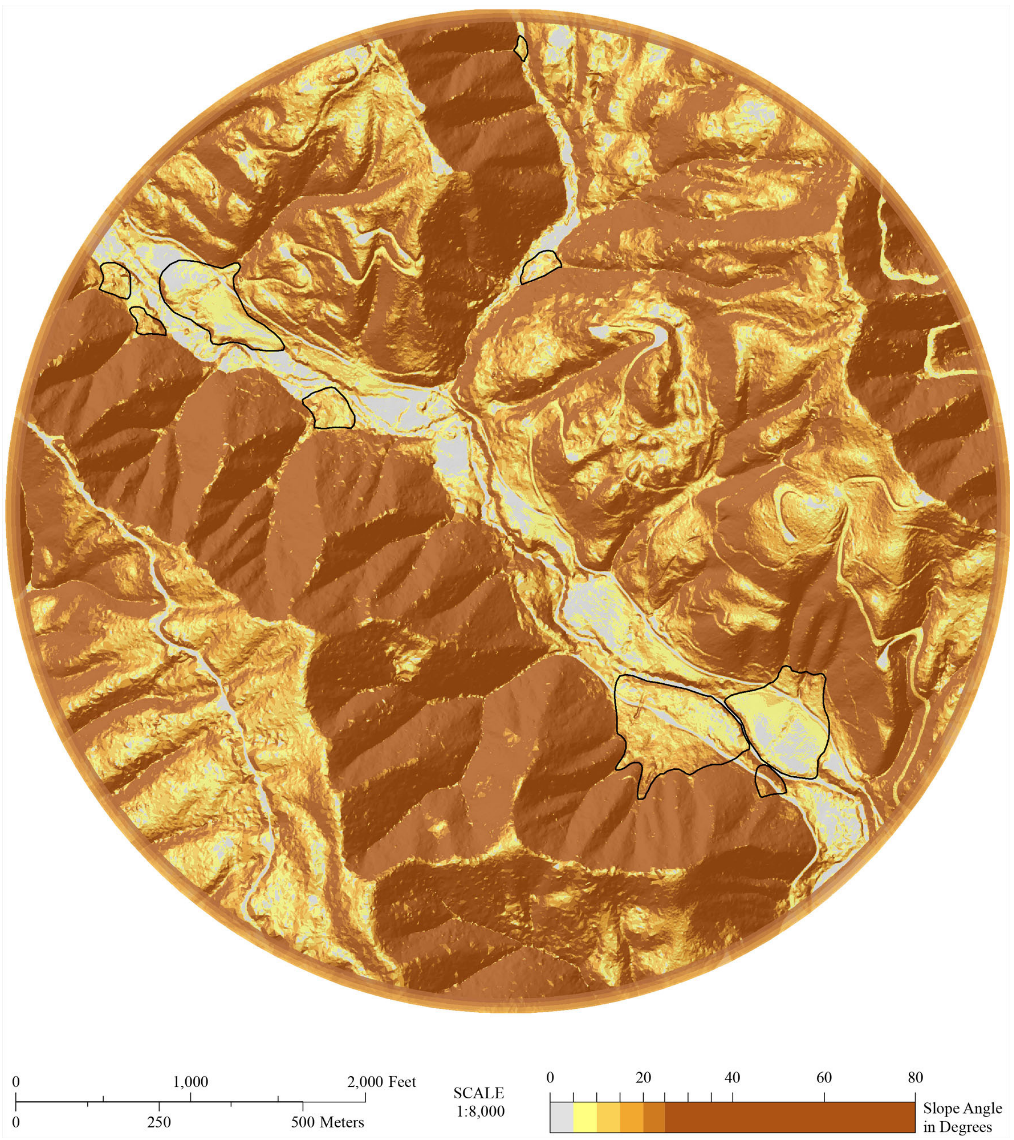


Figure 6. Example lidar-derived bare-earth digital elevation model (DEM) map displaying variance in slope where white/yellow areas have flat or very low slopes and orange/brown areas have steep slopes. Mapped debris flow fan areas are outlined in black and display a slight increase in slope versus the nearly flat adjacent areas.

5.2 North Fork Siuslaw watershed landslide inventory

The North Fork Siuslaw watershed has been examined for landslides several times prior to this study. Schlicker and others (1974) mapped landslides as part of DOGAMI Bulletin 85. They identified nine large landslides in the watershed. These nine landslides are included in SLIDO-2 (http://www.oregongeology.org/sub/slido/index.htm; Burns and others, 2011).

Graham (1985) mapped landslides in the upper quarter of the watershed as part of his aster's thesis. Graham found 11 landslide areas and 25 debris flows. Most of these landslides have dates of movement ranging from the late 1970s to the early 1980s.

During the 1996-1997 storms, 40 landslides were identified within the watershed by Siuslaw National Forest staff (Figure 1) (Hofmeister, 2000). These landslides are included as points in SLIDO-2 (http://www.oregongeology.org/sub/slido/index.htm; Burns and others, 2011).

Hofmeister and others (2002) modeled approximately 31.2 square miles (50%) of the watershed (65.7 square miles) as having a potential for future rapidly moving landslides (Figure 7).

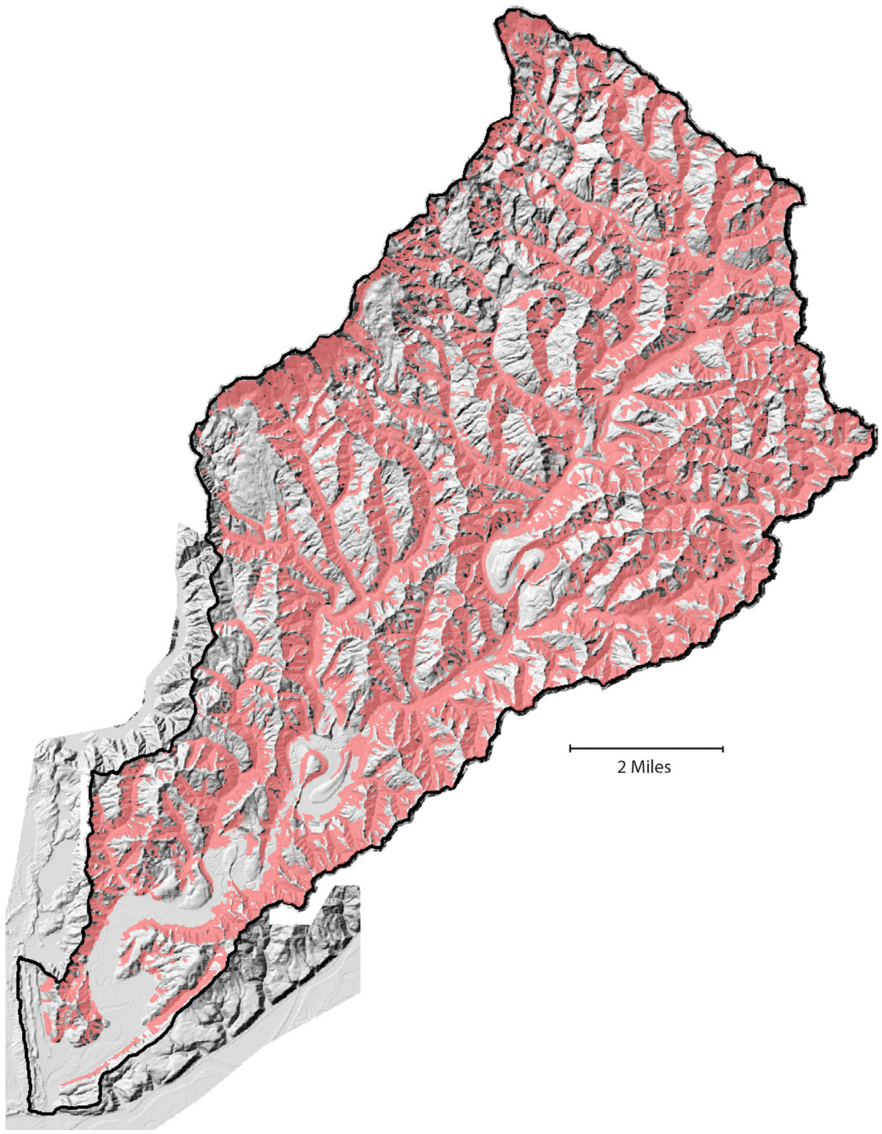


Figure 7. Potential rapidly moving landslide hazards (pink) in the North Fork Siuslaw watershed. The base map is a shaded relief digital elevation model (10-m DEM).

The new landslide inventory created as a part of this project is strikingly different from previous inventories (Figure 8; Plate 1). We found 1,323 landslide deposits within the watershed, and they cover an area of 15.8 square miles (26.5%). These landslides range in size from a couple hundred square feet to almost 30 million square feet (greater than 1 square mile). Ninety-seven of these landslides are shallow and 829 are deep. Three hundred seventy-nine are debris flow fan areas.

Six hundred ninety-eight of the 1,323 landslides are mapped as historic, that is, as having moved within the last 150 years. Twenty-four of these moved during the late 1970s to the early 1980s (Graham, 1985), and nineteen moved during the 1996-1997 storms (Burns and others, 2011). Thirty-eight landslides were identified as having moved between 2005 and 2009; the likely cause was the storm in December 2007. This publication includes the landslide inventory geodatabase as well as a map view (Figure 8; Plate 1) to assist users in understanding the regional extent and locations of the mapped landslides.

Summary — North Fork Siuslaw Watershed Landslide Inventory

Landslide deposits mapped	
Total	1,323
Shallow	97
Debris flow fan	379
Deep	829
Other (e.g., rock fall)	18
Time of movement	
Historic (within the last 150 years)	698
late 1970s to early 1980s	24
1996-1997 storm	19
2005–2009	38
Prehistoric	625
Area	
Minimum landslide	~200 ft^2
Maximum landslide	~30,000,000 ft^2
Watershed coverage	15.8 mi^2 (26.5%)

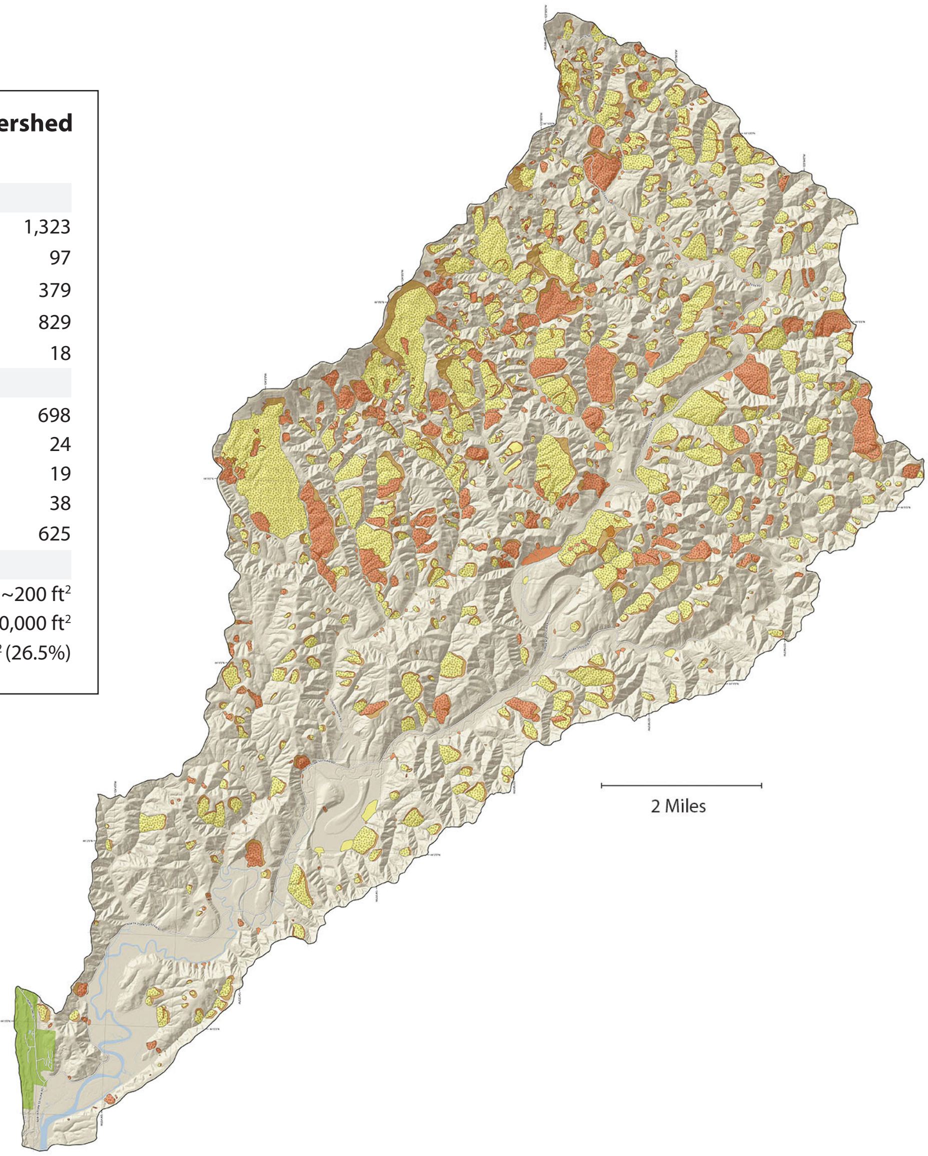


Figure 8. Lidar-derived hillshade image map and summary table of the 1,323 landslides included in the landslide inventory of the North Fork Siuslaw watershed. See Plate 1 for details and an explanation of the symbology.

The Tyee Formation in the North Fork Siuslaw watershed generally dips slightly toward the southwest; the attitude of the rock appears to be a major factor in landsliding. For example, many large deep landslides are on the west/southwest side of the ridges and fail toward the west/southwest, down the dip slope. Many drainages along the northeast side of the ridges, or the anti dip slope, are very steep and have debris flow fans at the mouths of the drainages (Figure 9 and Plate 1).

We also noticed a change in landslide size and density above and below approximately 44°5′0″N latitude (Plate 1). This may be due to a flattening of the dip angle in the southern part of the watershed.

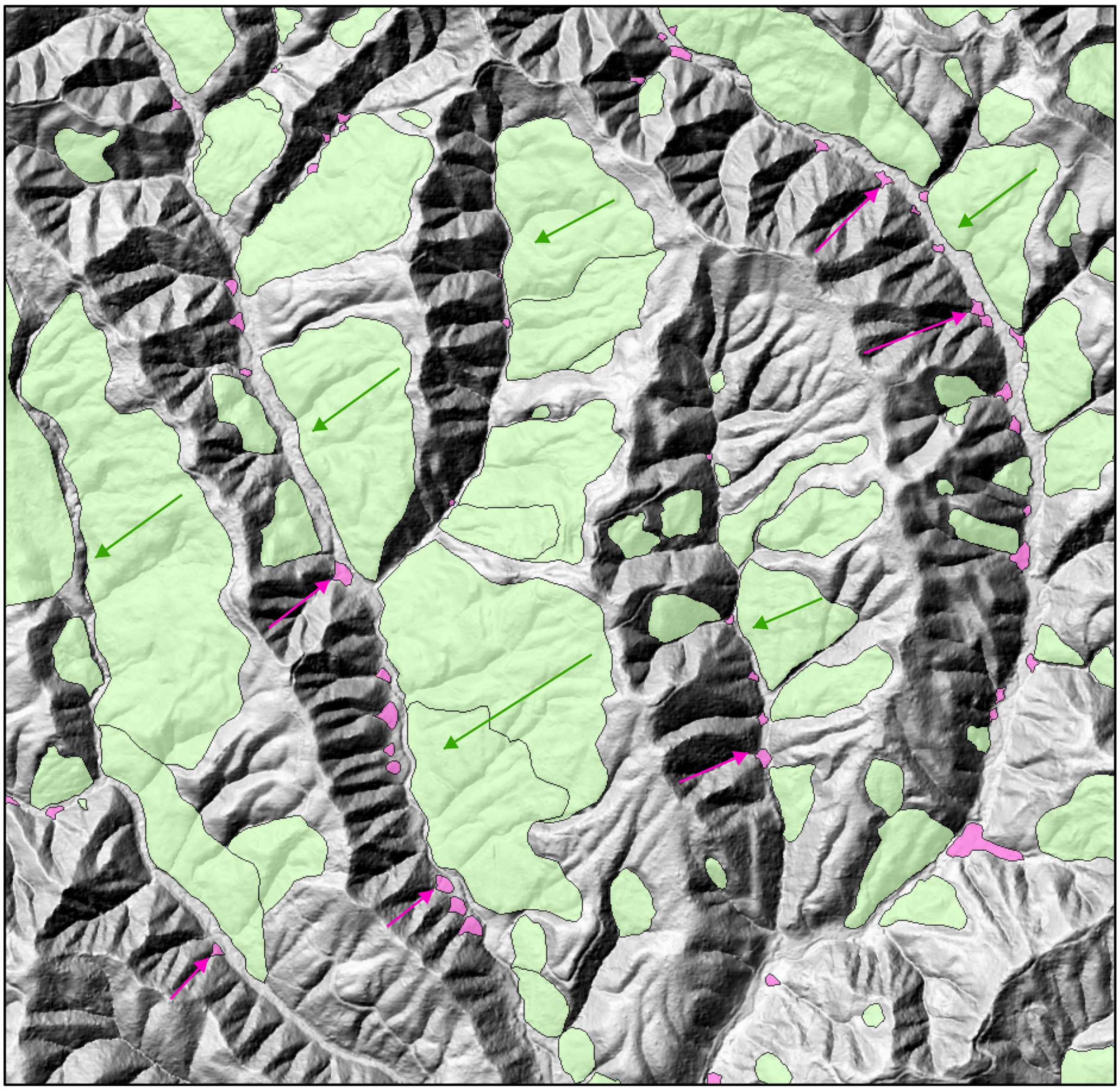


Figure 9. Lidar-derived shaded relief digital elevation model (DEM) map of central portion of the North Fork Siuslaw watershed showing mostly large deep landslides in green and debris flow fans in pink. Green and pink arrows of direction of movement. Area shown is approximately four square miles.

5.3 Big Elk Creek watershed landslide inventory

The Big Elk Creek watershed has also been examined for landslides several times prior to this study. Schlicker and others (1973), Wang and others (2001), Priest and Allan (2004), and McClaughry and others (2010) mapped landslides as part of DOGAMI studies. They identified 37 mostly large landslides within the watershed. These 37 landslides are included in SLIDO-2 http://www.oregongeology.org/sub/slido/index.htm (Burns and others, 2011).

During the 1996-1997 storms, 139 landslides were identified as points in the watershed by the BLM, FEMA, Lincoln County, and Siuslaw National Forest staff (Figure 1) (Hofmeister, 2000). These landslides are included in SLIDO-2 as points (http://www.oregongeology.org/sub/slido/index.htm (Burns and others, 2011).

Hofmeister and others (2002) modeled approximately 50 square miles (56%) of the watershed (89 square miles) as having a potential for rapidly moving landslides (Figure 10).

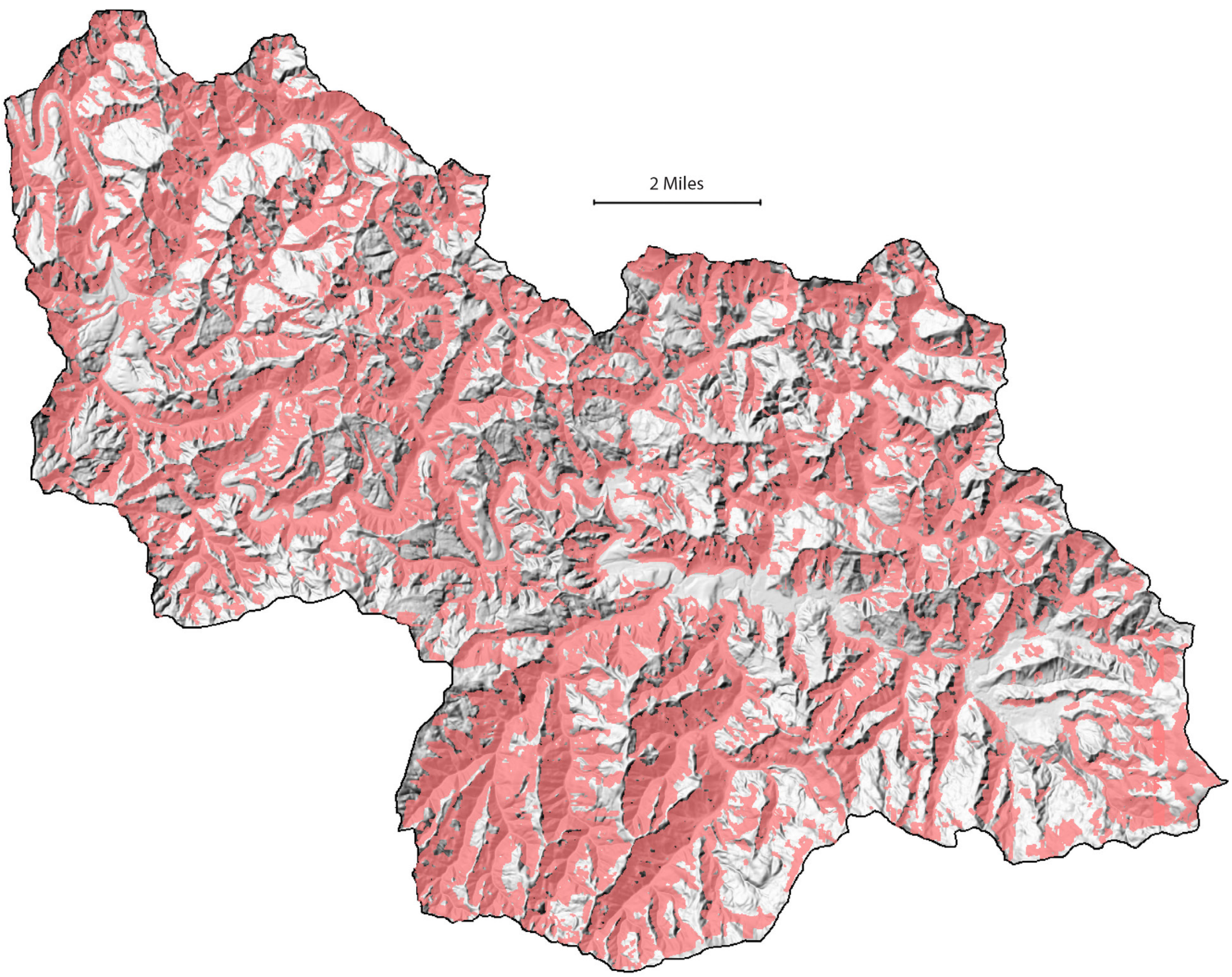


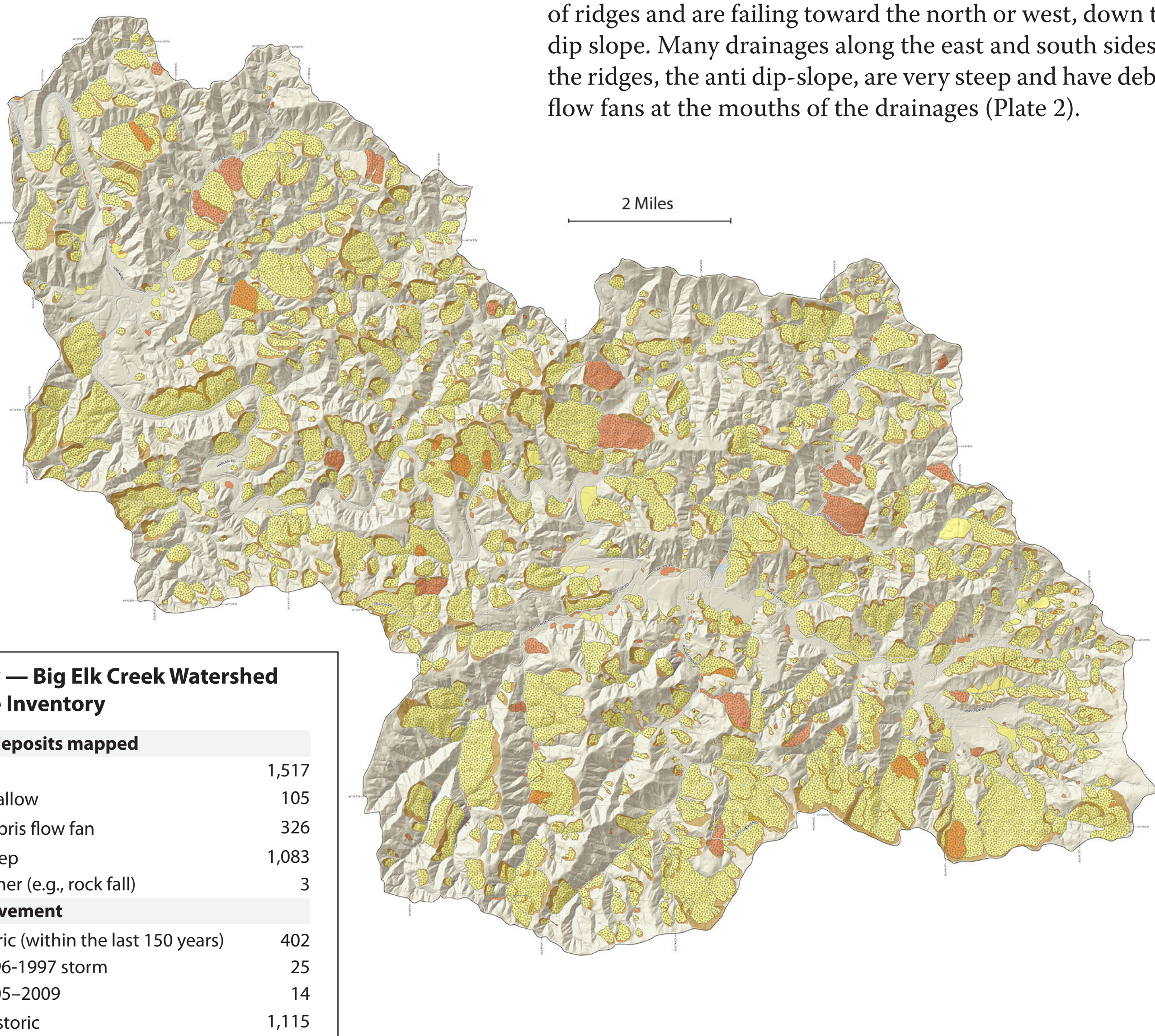
Figure 10. Potential rapidly moving landslide hazards (pink) in the Big Elk Creek watershed. The base map is a shaded relief digital elevation model (10-m DEM).

The new landslide inventory created as a part of this project is again strikingly different from previous inventories. We found 1,517 landslide deposits within the watershed, and they cover 32.5 square miles (37%) (Figure 11; Plate 2). These landslides range in size from a couple hundred square feet to almost 18 million square feet (greater than one-half square mile). One hundred five of these landslides are shallow, and 1,083 are deep. Three hundred twenty-six are debris flow fan areas.

Four hundred two of the 1,517 landslides are mapped as historic, that is, as having moved within the last 150 years. Twenty-five moved during the 1996-1997 storms (Burns and others, 2011).

Fourteen landslides were identified as having moved between 2005 and 2009; the likely cause was the storm in December 2007. This publication includes the geodatabase which contains the new landslide inventory. This publication includes the landslide inventory geodatabase as well as a map (Figure 11; Plate 2) view to assist users in understanding the regional extent and locations of the mapped landslides.

As in the North Fork Siuslaw watershed, the Tyee Formation within the Big Elk Creek watershed appears to influence landsliding. However, here the rock is generally dipping slightly toward the north and/or west. For example, many large deep landslides are on the west or north sides of ridges and are failing toward the north or west, down the dip slope. Many drainages along the east and south sides of the ridges, the anti dip-slope, are very steep and have debris flow fans at the mouths of the drainages (Plate 2).



Summary — Big Elk Creek Watershed Landslide Inventory

Landslide deposits mapped	
Total	1,517
Shallow	105
Debris flow fan	326
Deep	1,083
Other (e.g., rock fall)	3
Time of movement	
Historic (within the last 150 years)	402
1996-1997 storm	25
2005–2009	14
Prehistoric	1,115
Area	
Minimum landslide	~200 ft²
Maximum landslide	~18,000,000 ft²
Watershed coverage	32.5 mi² (37%)

Figure 11. Lidar-derived hillshade image map and Summary table of the 1,517 landslides included in the landslide inventory of the Big Elk Creek watershed. See Plate 2 for details and an explanation of the symbology.

5.4 Limitations

The datasets for this project were created by following some of the latest methods. However, inherent limitations in the methodology underscore that these data and maps are designed for regional applications; the data and maps should not be used as an alternative to site-specific studies in critical areas.

General limitations of this kind of mapping, as discussed by Burns and Madin (2009), are:

- 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.
- Burns and Madin (2009) recommended 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.
- 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.
- 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.
- 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.
- Earthwork related to development on hillsides can remove the geomorphic expressions of past landsliding. This can result in landslides being missed in the inventory.
- 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.

Limitations of particular importance to this study are:

- Landslides mapped in the North Fork Siuslaw and the Big Elk Creek watersheds using the lidar base were not checked in the field. Field checking of mapped landslide polygons should be performed in the future.
- Some sparsely spaced ground points resulted in less than ideal bare-earth DEMs. Because lidar-based landslide mapping is highly dependent on the bare-earth DEM, some landslides, especially smaller ones in areas with sparse ground points, may have been missed.

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