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

OPEN FILE REPORT O-12-05

REGIONAL LANDSLIDE HAZARD MAPS OF THE CITY OF SILVERTON, MARION COUNTY, OREGON

Intergovernmental Agreement with the City of Silverton, Oregon
(IA no. 41460-11242008)

by William J. Burns[1] and Katherine A. Mickelson[1]

2012

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NOTICE

The Oregon Department of Geology and Mineral Industries is publishing this map because the subject matter is consistent with the mission of the Department. The map is not intended to be used for site specific planning. It may be used as a general guide for emergency response planning. Maps in this publication depict landslide hazard areas on the basis of limited data as described further in the text. **The maps cannot serve as a substitute for site-specific investigations by qualified practitioners.** Site-specific data may give results that differ from those shown on the maps.

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1.0 EXECUTIVE SUMMARY

On December 30, 2008, the Oregon Department of Geology and Mineral Industries (DOGAMI) entered an intergovernmental agreement with the City of Silverton, Oregon (IA no. 41460-11242008) to perform regional landslide hazard evaluation of the City of Silverton.

Deliverables of this study include the following:

- this report text
- hazard maps:
  - landslide inventory map (Plate 1)
  - shallow-landslide susceptibility map (Plate 2)
  - deep-landslide susceptibility map (Plate 3)
- geographic information systems (GIS) files:
  - landslide inventory
  - shallow-landslide susceptibility
  - deep-landslide susceptibility

The *Protocol for Inventory Mapping of Landslide Deposits from Light Detection and Ranging (Lidar) Imagery* (Burns and Madin, 2009) was used to create a landslide inventory of the City of Silverton area; 110 landslide deposits were located during this project. Of these, 25 are within or directly adjacent to the city. Of these 25, nine were classified as shallow, seven as deep, and two as debris flow deposits. The other seven (of the 25) are areas of rock fall and/or debris slide deposits.

The *Protocol for Shallow-Landslide Susceptibility Mapping* (Burns and others, 2012) was used to create a shallow-landslide susceptibility map of the City of Silverton area. Approximately 5% of the City of Silverton is classified as highly susceptible to shallow landslides, 19% as moderately susceptible to shallow landslides, and 76% as less susceptible to shallow landslides.

We followed the deep-landslide susceptibility mapping method outlined by Burns (2008) to create a deep-landslide susceptibility map of the City of Silverton. Approximately 0.2% of the City of Silverton is classified as highly susceptible, 1% as moderately susceptible, and 99% as less susceptible to deep landslides.

We developed landslide inventory and landslide susceptibility maps with the best available data and documented methods, but several limitations underscore that these maps are designed for regional applications and should not be used as an alternative to site-specific studies in critical areas. These limitations are described in detail on Plates 1–3.

These maps are intended to provide users with basic information regarding landslides and the susceptibility to landslides within the mapped area. The data are particularly suitable for incorporation and into regional GIS databases for a multitude of purposes. These include but are not limited to city and county hillside development ordinances, issuance of building permit conditions, public works planning and operations, and environmental and sustainability issues. We reiterate that these data are not appropriate for site-specific evaluations.

The City of Silverton has a relatively low to moderate landslide hazard, when compared to other communities in Oregon. About one twentieth of the city is underlain by historic and prehistoric landslide deposits. However, some mapped landslide deposits (in particular, rock fall and/or debris slide deposits) are overlain by development. This relationship indicates a significant landslide risk exists in the City of Silverton, and thus there exists a strong need for landslide risk management. Landslides adjacent to Silver Creek Reservoir also indicate a significant risk.

2.0 SIGNIFICANCE OF THE PROBLEM

Landslides are one of the most widespread and damaging natural hazards in Oregon. In order to begin reducing losses from landslides (mitigation), areas of landslide hazard must first be located. The first step in landslide hazard identification is to create an inventory of past (historic and prehistoric) landslides. The inventory can then be used to create susceptibility maps that display areas at risk for landslides.

3.0 PURPOSE AND SCOPE

The purpose of this study is to evaluate the regional relative landslide hazard and to provide recommendations to the City of Silverton (Figure 1). Seismic, civil, and environmental evaluation of any kind are beyond the scope of this project.

We performed our services in accordance with the intergovernmental agreement with the City of Silverton (IA No. 41460-11242008). DOGAMI is not responsible for independent conclusions, opinions, or recommendations made by others from information provided in this report.

Considering the dynamic environment in Oregon, the inherent risks associated with development in hilly areas, and incomplete knowledge of geologic hazard processes, we warn that our report does not assure any safety or warranty from geologic hazards. The maps in this study were developed with the best available data and documented protocols; however, several limitations underscore that these maps are designed for regional applications and should not be used as an alternative to site-specific studies. These limitations are described in detail on Plates 1–3.

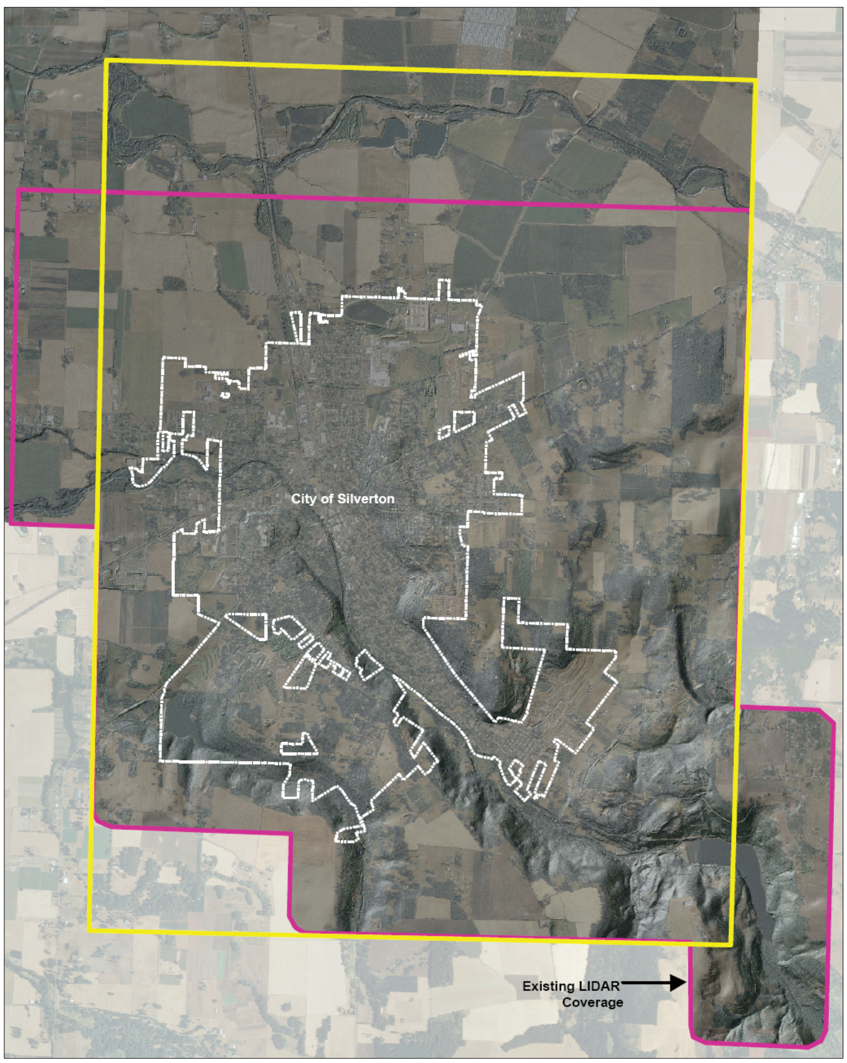


Figure 1. Study area, City of Silverton, Marion County, Oregon (outlined in pink). Outlined in yellow is the extent of Plates 1-3 included in this study.

4.0 CREATION OF THE HAZARD MAPS

As part of this study, we created three landslide hazard maps: 1) lidar-based landslide inventory, 2) shallow-landslide susceptibility, and 3) deep-landslide susceptibility. The methods employed to create these maps are described below.

4.1 Lidar-Based Landslide Inventory

Recently, very high resolution, high-accuracy digital elevation models (DEM) developed by using light detection and ranging (lidar) data have become available for some parts of Oregon. These new data give us a much better image of the surface geomorphology, allowing identification of 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, transverse ridges, and snouts (Burns and Madin, 2009). Such features can be used to identify landslides with a high level of certainty and to map them accurately. In the past, most accurate, higher-certainty, landslide maps were created using a combination of aerial photography and extensive field survey. The use of lidar-derived bare-earth DEMs is the key to the landslide mapping performed in this study.

Prior to beginning lidar-based mapping of landslides in the Silverton area, we reviewed two landslide inventories: 1) the 1996-1997 storm events inventory (DOGAMI Special Paper 34 [Hofmeister, 2000]) and the Statewide Landslide Information Database for Oregon (SLIDO-1) (Burns, and others, 2008). The latest geologic maps of the area, (DOGAMI Oregon Geologic Data Compilation, Ma and others, 2009) were also reviewed. No landslides from any of these sources were identified within the City of Silverton (Figure 2). We also reviewed DOGAMI Interpretive Map 22 (IMS-22) and found that many of the steep slope areas were identified in this publication as potential rapidly moving landslide hazard zones (Figure 2) (Hofmeister and others, 2002).

After review of previous regional landslide hazard studies, we mapped the entire study area (which encompasses the entire City of Silverton) using lidar-derived DEMs and DEM derivatives including shaded relief (hillshades), slope maps, and topographic contours. In addition to the lidar-derived images, we used an orthophotograph of similar age to the lidar data to help differentiate between some man-made and natural landforms. We identified landslides solely from ground surface morphology. Morphologic features include head scarps, hummocky topography, convex and concave slope areas, offset drainages, flank shear offsets, and internal scarps. We created the inventory following the protocol defined by Burns and Madin (2009).

Because landslides and landslide features are not all the same size, we mapped at several different scales, in this order:

- 1:24,000 scale (the native scale of a standard printed 7.5 minute U.S. Geological Survey topographic quadrangle)
- 1:10,000
- 1:4,000

Spatial data and tabular data were mapped into a GIS. Spatial data include the following four elements:

- polygon (outline) of the mapped landslide deposit
- polygon (outline) of the landslide head scarp
- line of the uppermost extent of the head scarp
- lines of internal scarps

However, all four of these features may not have been present or determinable at every landslide.

Kinds of tabular data collected are shown in Table 1. Some of these tabular data may not have been present or determinable at every landslide. Some fields are described in more detail on Plate 1.

One important tabular datum in the landslide inventory is the estimated depth of failure, which was calculated for each identified landslide as shown in Figure 3 (Burns and others, 1998; Burns, 1999; Burns and Madin, 2009).

Using estimated failure depth, we classified each landslide as deep or shallow seated. This differentiation is necessary because different models are used to calculate or estimate regional stability or susceptibility for different depths and for different types of landslides. There is no widely accepted value of division between deep and shallow landslides, so we based our value on the combination of several factors and several other studies (Sidle and Ochiai, 2006; Burns, 1999; Harp and others, 2006). We selected a division value of 15 ft (4.5 m) between shallow and deep landsliding. Burns and Madin (2009) discussed the selection of this cutoff value.

After completing lidar-derived DEM mapping and tabular database entry, we performed ground reconnaissance to field verify suspected landslide features. Observations made during the reconnaissance were used to revise the lidar-based landslide inventory map, as appropriate.

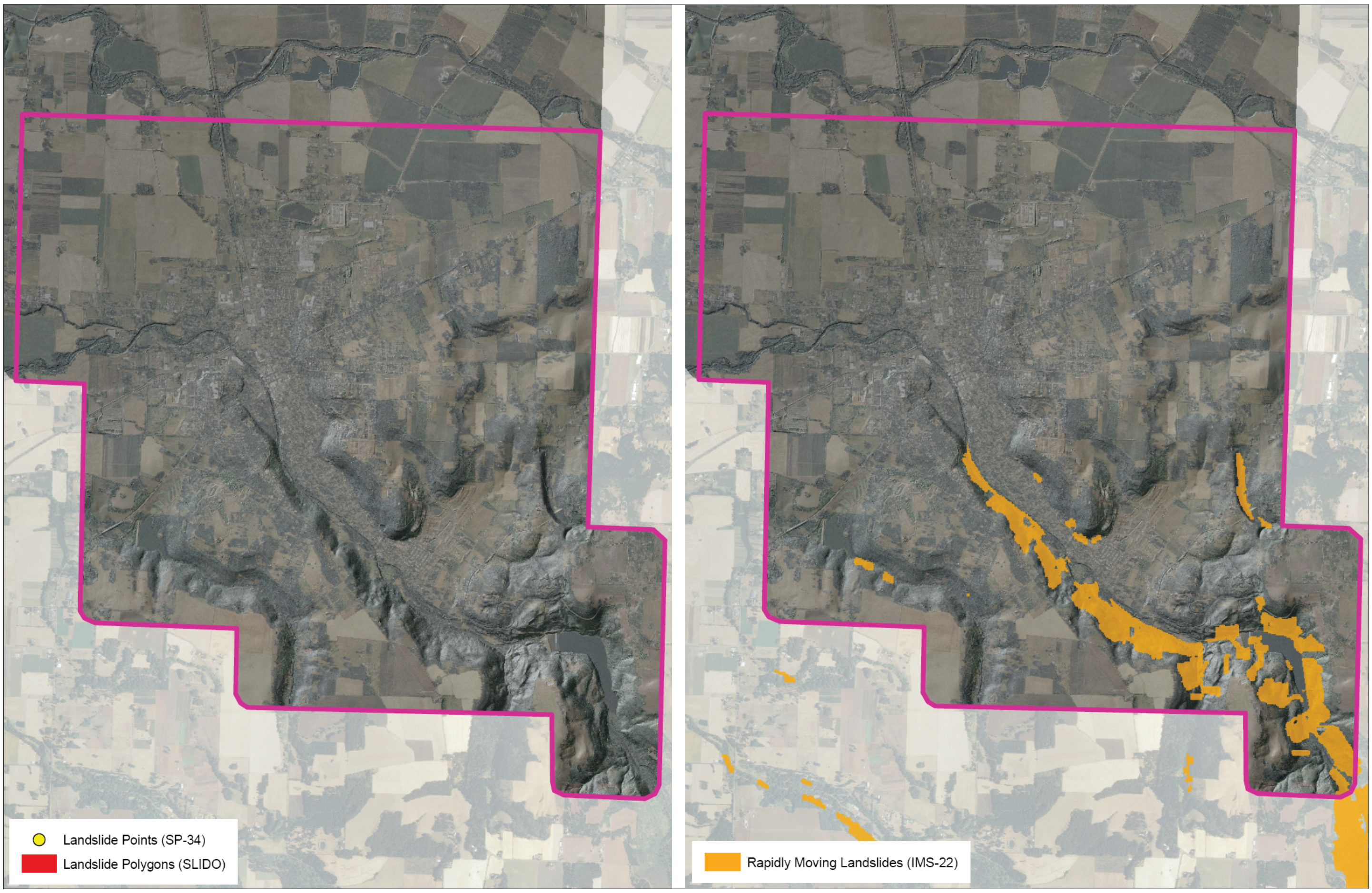


Figure 2. (left) Map of previously identified landslides from DOGAMI publications Oregon Geologic Data Compilation, release 5 (OGDC-5) (Ma and others, 2009), Special Paper 34 (SP-34) (Hofmeister, 2000), and Statewide Landslide Inventory Database for Oregon, release 1 (SLIDO-1) (Burns and others, 2008); and (right) map of potential debris flow hazard areas from DOGAMI Interpretive Map 22 (Hofmeister and others, 2002). Note that no landslide points (SP-34) or landslide polygons (SLIDO-1) were identified within the study area (pink outline). However, some very steep slopes were identified as rapidly moving landslide hazard areas (IMS-22).

Table 1. Tabular data fields used for lidar-based landslide inventory.

Field Name	Abbreviated Code	Brief Description
Identification	ID	numeric string
Quadrangle name	QUADNAME	7.5 minute quadrangle name
Unique identification	UNIQUE_ID	"QUADNAME"_"ID"
Mapper name	MAPPER_NAM	name of mapper
Type of movement	Type_Move	type of movement
Movement classification	MOVE_CLASS	classification name
Movement classification code	MOVE_CODE	classification code
Confidence of interpretation	CONFIDENCE	confidence of identification
Estimated age	AGE	estimated age
Date of last movement	DATE_MOVE	date of last known movement
Landslide name	NAME	landslide name
Geology	Geol	geologic unit
Adjacent slope	SLOPE	adjacent slope angle
Head scarp height	HSHEIGHT	change in elevation from bottom to top of head scarp or change in elevation from top to toe of fan
Failure depth	FAIL_DEPTH	estimated failure depth
Fan depth	Fan_DEPTH	estimated depth of fan
Deep-shallow	DEEP_SHAL	deep or shallow seated
Horizontal distance HS to IS1	HS_IS1	horizontal distance from head scarp to internal scarp no.1
Horizontal distance IS1 to IS2	IS1_IS2	horizontal distance from internal scarp 1 to internal scarp 2
Horizontal distance IS2 to IS3	IS2_IS3	horizontal distance from internal scarp 2 to internal scarp 3
Horizontal distance IS3 to IS4	IS3_IS4	horizontal distance from internal scarp 3 to internal scarp 4
Average horizontal distance between internal scarps	HDAVE	average horizontal distance between internal scarps
Size of landslide deposit	AREA	size of landslide deposit
Volume of landslide deposit	VOL	volume of landslide deposit

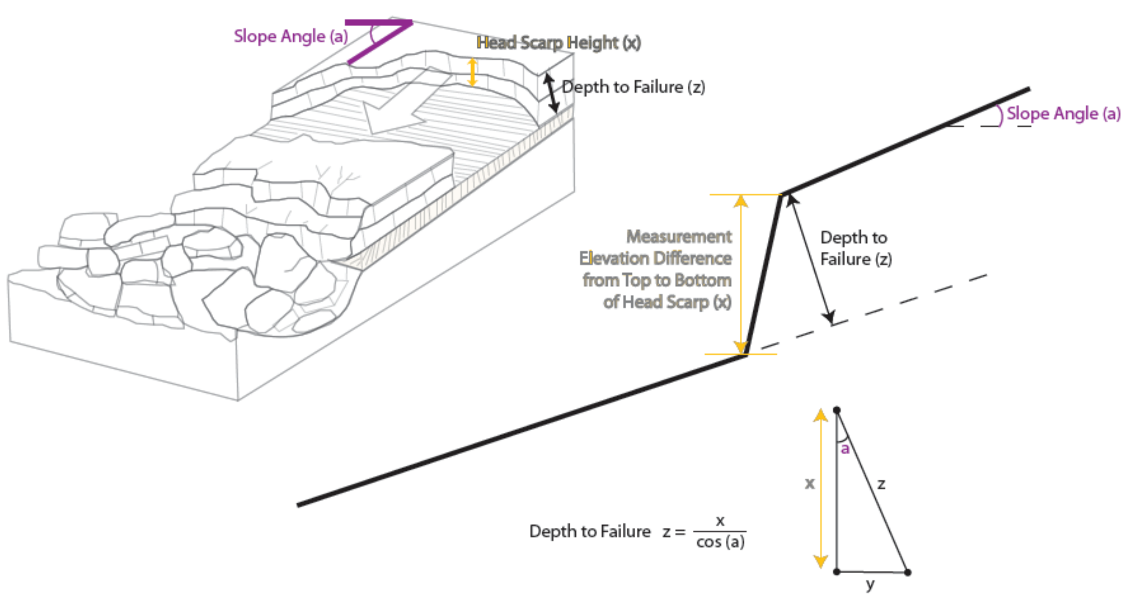


Figure 3. Diagram and equation for calculation of estimated depth to failure.

To assist visualization, we created a 1:8,000-scale map (Plate 1; reduced copy in Figure 4) that displays lidar-based landslide inventory data (Silverton_LSdeposits.*, Silverton_LSheadscarps.*, and Silverton_LSscarps.*; these GIS files are provided as part of this report). This map cannot serve as a substitute for site-specific investigations by qualified practitioners. Site-specific data may give results that differ from those shown on this map. Several other limitations are listed on Plate 1.

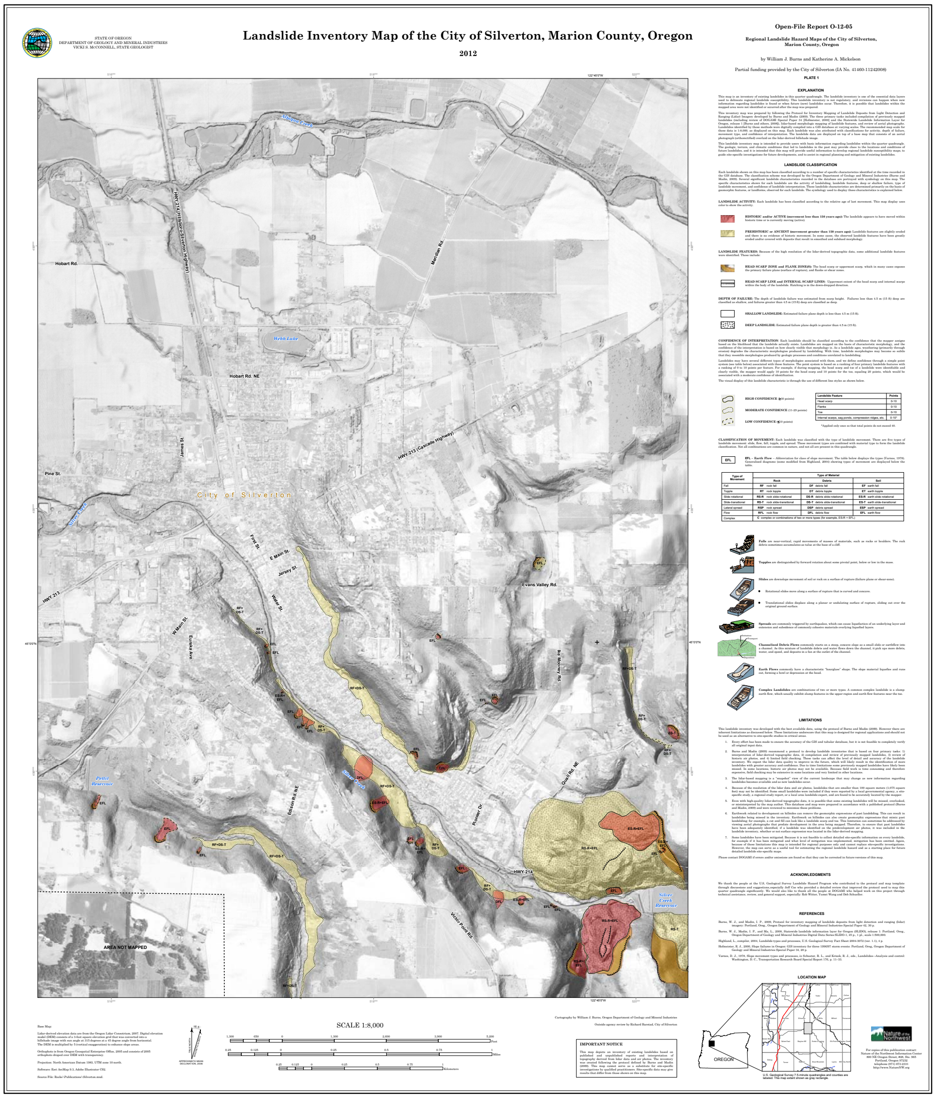


Figure 4. Landslide inventory map (reduced copy of Plate 1 of this report) of the study area, City of Silverton, Marion County, Oregon.

4.2 Shallow-Landslide Susceptibility

The *Protocol for Shallow-Landslide Susceptibility Mapping* (Burns and others, 2012) was used to create the shallow-landslide susceptibility map. The four main components used in the protocol are:

- **Inventory Zone Map** – Mapped shallow-landslides from an SP-42 inventory
- **FOS Class Map** – Map of Factor of Safety classes (high, moderate, and low)
- **Head Scarp Buffer Map** – Map of Special Paper 42 inventory head scarp buffers
- **FOS Buffer Map** – Map of moderate and high FOS Class buffers

These four factors were then combined into final susceptibility hazard zones. All shallow (slides, flows, and spreads) were queried out of the lidar-based landslide inventory database and saved to a separate GIS file.

To calculate the Factor of Safety (FOS) for shallow landsliding, we used the infinite slope equation shown in Figure 5. Because the infinite slope equation for regional stability analysis is limited to a grid type analysis (i.e., the results are a calculated FOS for each individual grid cell, which does not consider the potential impact of adjacent slopes, etc.), we took a conservative approach in most steps to calculate the FOS. The limitations are discussed in greater detail later in this section, on Plate 2, and by Burns and others (2012).

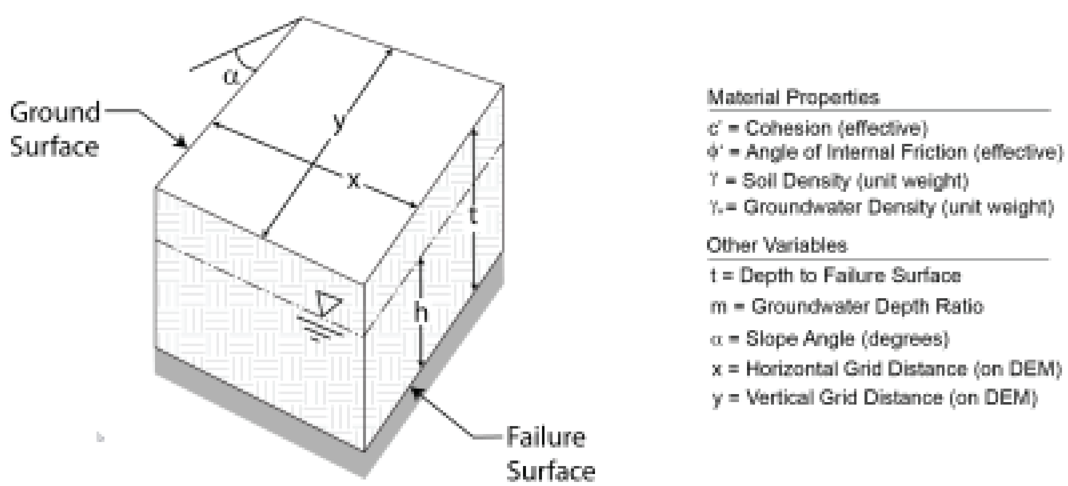
Several data sets are needed to calculate FOS throughout the area:

- Geology – geotechnical material properties
- Depth to failure surface
- Groundwater height above failure surface
- Slope angle

Material properties consist of cohesion, angle of internal friction, soil density, and water density. Because these properties can vary from geologic unit to geologic unit, we constructed a digital geologic map that contains the material properties for each unit (Figure 6). These properties can also vary within a particular geologic unit, so conservative values were used for each unit.

Because material properties are not readily available for the region, we constructed and used a set of conservative values (Table 2).

The maximum depth to failure surface, as defined by the cutoff between shallow and deep landslides, is 4.5 m (15 ft). The groundwater parameter can vary widely spatially and with time. Because of these potential variations, we selected a worst case scenario (most conservative) approach: complete saturation, or *z*, equals *h* (Figure 5).



$$\text{Factor of Safety (FOS)} = \frac{c'}{\gamma\, t \sin\alpha} + \frac{\tan\phi'}{\tan\alpha} - \frac{m\, \gamma_w \tan\phi'}{\gamma \tan\alpha}$$

Figure 5. Infinite-slope analysis: diagram, parameters, and equation (Burns and others, 2012; Harp and others, 2006).

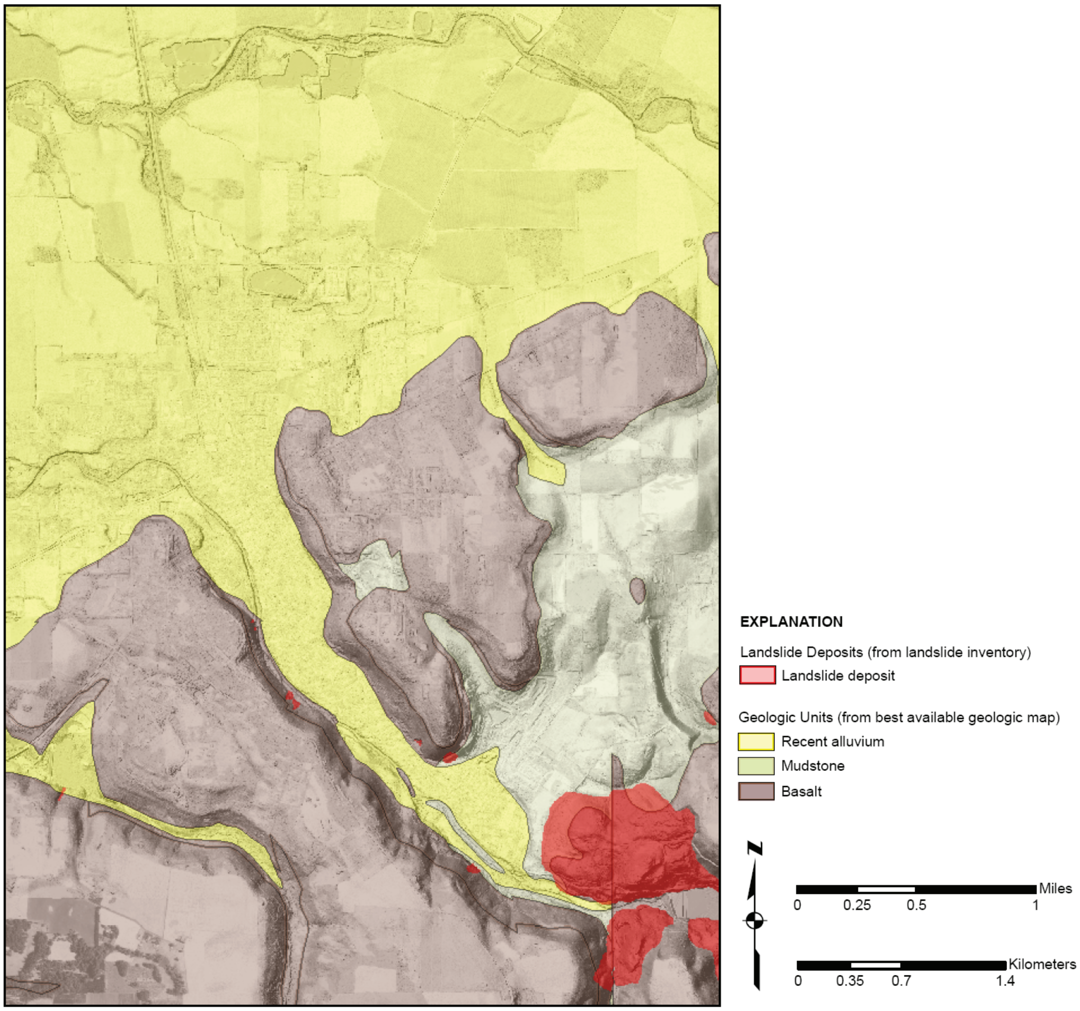


Figure 6. Geologic-material properties map of the City of Silverton (Ma and others, 2009).

Table 2. Conservative typical soil and rock material properties (Harp and others, 2006; Cornforth, 2005; Denning, 1994).

	Common Lithology Description	Common Unit or Formation Names	Common Unit Label	Raster Value GeolCode	Angle of Internal Friction (ϕ) (degrees)	Cohesion (c) (kPa)	Cohesion (c) (lb/ft2)	Unit Weight (sat) (kN/m3)	Unit Weight (sat) (lb/ft3)	Slope FOS>1.5	Slope FOS>1.25
Cohesionless Soils											
Landslide Deposit (shallow failure)	Sheared landslide debris (silts, clays, sands)	Landslide	Qls		10	0	0	19	122	3.0	4.0
Landslide Deposit (deep failure)	Shearing mainly along deep failure plane	Landslide, colluvium	Qls, Qc	1	28	0	0	19	122	9.5	11.5
Fill	Sand, silt, gravel, debris mixtures	Artificial Fill	Fill, Qf	2	30	0	0	19	122	10.5	12.5
Recent Alluvium (fine grained)	Silt, sand	Quaternary Alluvium, loess	Qal, Qff, Ql	3	30	0	0	19	122	10.5	12.5
Recent Alluvium (coarse grained)	Sand, gravel, boulders	Quaternary Alluvium, gravel fan	Qal, Qcf	4	34	0	0	19	122	12.0	14.5
Cohessive Soils											
Glacial Till	Sand, silt, clay, gravel	Glacial Till	Qva, Qt	5	34	10	209	19	122	16.5	19.5
Residual Soil on Igneous Rock	Silty Clay with Boulders	Columbia River Basalt	Tcr	6	28	24	501	19	122	20.0	25.0
Residual Soil on Sedimentary Rock	Silty Sand, Sandy Silt, Silty Gravel	Troutdale Formation	Tt	7	30	10	209	19	122	14.5	17.5

FOS is Factor of Safety.

The high-resolution lidar-derived digital elevation model (DEM) was used to create a map of slope angles for each grid cell (Figure 7), satisfying the slope angle parameter in the infinite slope equation.

Once the FOS was calculated, we removed isolated small elevation changes from the resulting FOS map. This was done by calculating the range of elevation changes (i.e., flat areas, slopes, to vertical escarpments) within a horizontal distance of 15 ft of any grid cell. After the range of elevation change had been calculated, all cells with values less than 4 ft were removed from the high or moderate FOS class (Burns and Madin, 2009).

Because there are many limitations to regional stability analysis using the infinite slope equation and unknowns due to general lack of material properties data spatially, we applied a 2:1 horizontal to vertical distance ratio (2H:1V; Figure 8) buffer to both the head scarp and the FOS, as described below.

Most landslides tend to leave a near-vertical head scarp above the failed mass. Commonly, this head scarp area will fail retrogressively or a separate landslide will form above the head scarp due to loss of resisting forces. Generally, the area above the head scarp has a relatively low slope angle; thus, the Factor of Safety calculated using the infinite-slope equation on a grid is relatively high — indicating a low susceptibility of future failure. To account for the increase in susceptibility of this area above the head scarp, which is missed when using the infinite-slope equation alone, we used a 2:1 horizontal to vertical distance ratio (2H:1V) head scarp buffer (Figure 9).

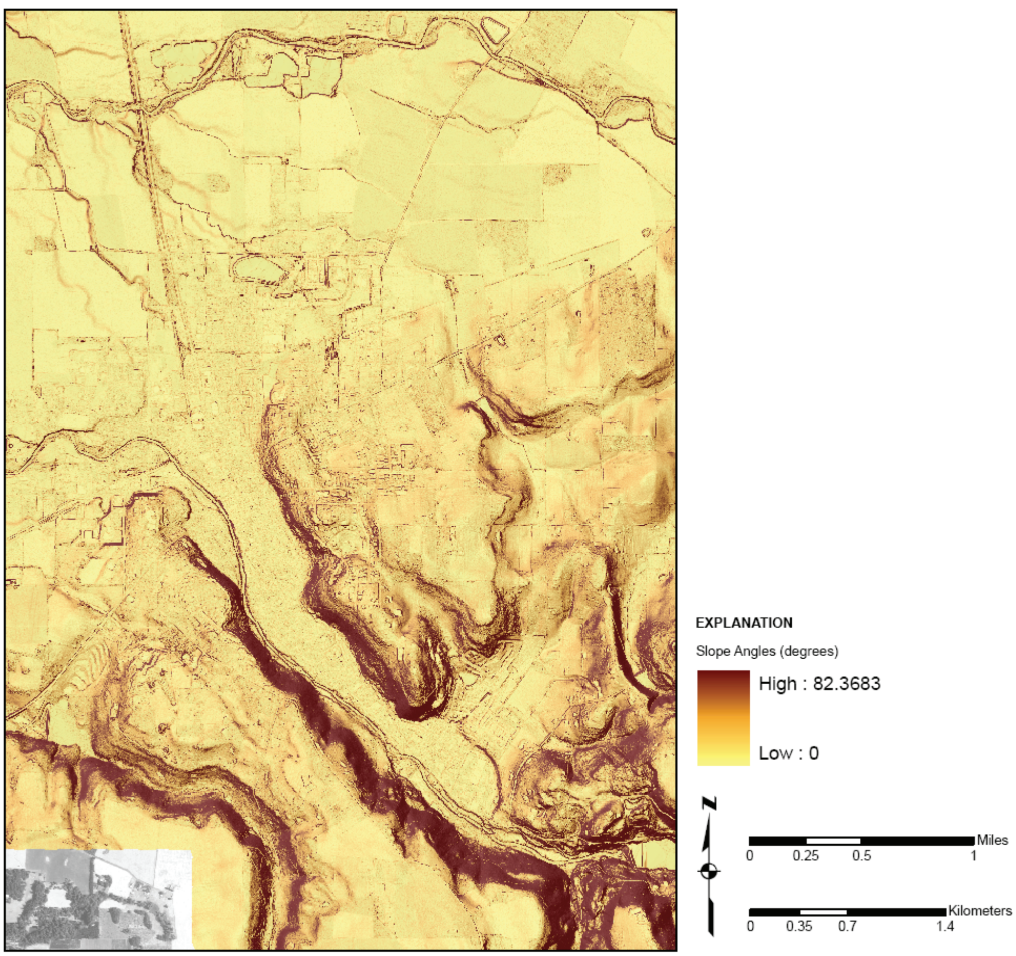


Figure 7. Slope map of the City of Silverton, Oregon, created from lidar-derived digital elevation model.

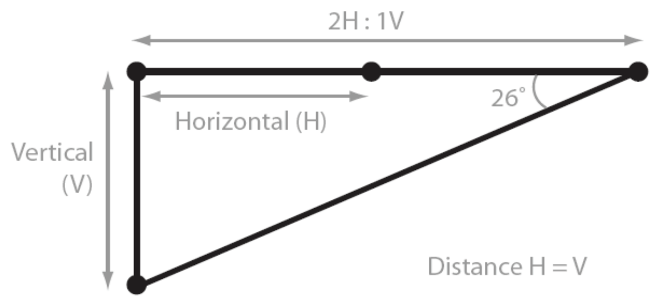


Figure 8. Diagram of the 2:1 horizontal to vertical distance ratio (2H:1V) used to create head scarp and Factor of Safety buffers.

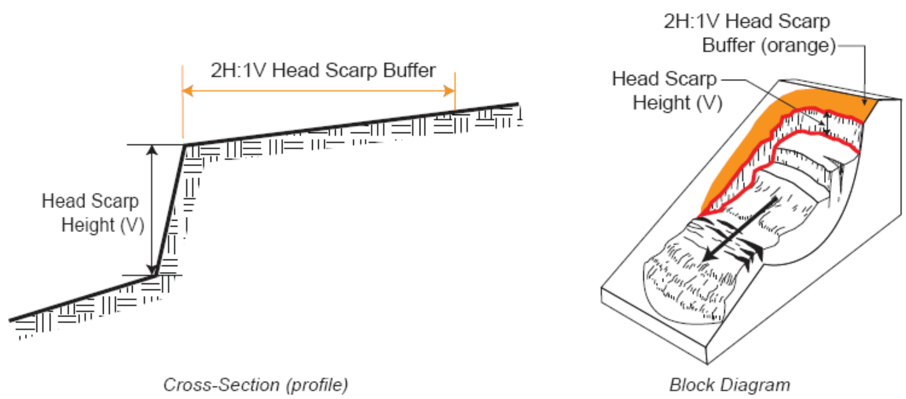
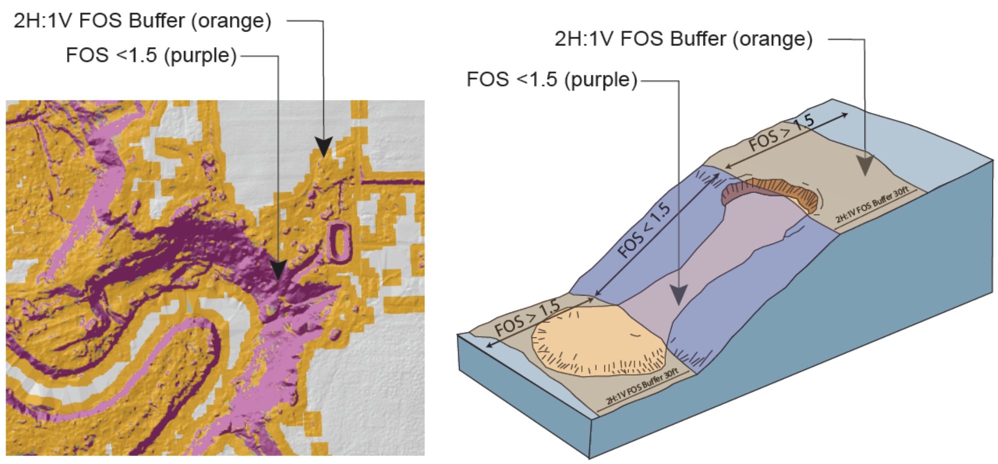


Figure 9. Diagram of the 2:1 horizontal to vertical distance ratio (2H:1V) head scarp buffer.

Because use of the infinite slope equation for regional stability analysis is limited to a grid type analysis (i.e., the results are a calculated FOS for each individual grid, which does not consider the potential impact of adjacent slopes, etc.), we applied a buffer to all areas with a calculated FOS less than 1.5 or the areas considered to be potentially unstable. This buffer was applied all around areas with a calculated FOS less than 1.5 as shown in Figure 10.

To create the final shallow-landslide hazard zones, we combined several of the contributing factors (Table 3).

The shallow-landslide susceptibility zones are presented on a 1:8,000-scale map (Plate 2; see reduced copy in Figure 11) (LSshallow-suscept.*; these GIS files are provided as part of this report). We created the susceptibility zones following the method described in this paper and the protocol defined by Burns (2008). This map cannot serve as a substitute for site-specific investigations by qualified practitioners. Site-specific data may give results that differ from those shown on this map. Several other limitations are listed on Plate 2.



Map View

Block-Diagram View

Figure 10. Diagram of the 2:1 horizontal to vertical distance ratio (2H:1V or 2H:1*z*) buffer applied to all Factor of Safety (FOS) less than 1.5.

Table 3. Final hazard zone matrix for shallow landslides.

Contributing Factors	Final Hazard Zone		
	High	Moderate	Low
Factor of Safety (FOS)	less than 1.25	1.25 - 1.5	greater than 1.5
Landslide Deposits & Head Scarps	included	—	—
Buffers	2H:1V (head scarps)	2H:1V (FOS less than1.5)	—

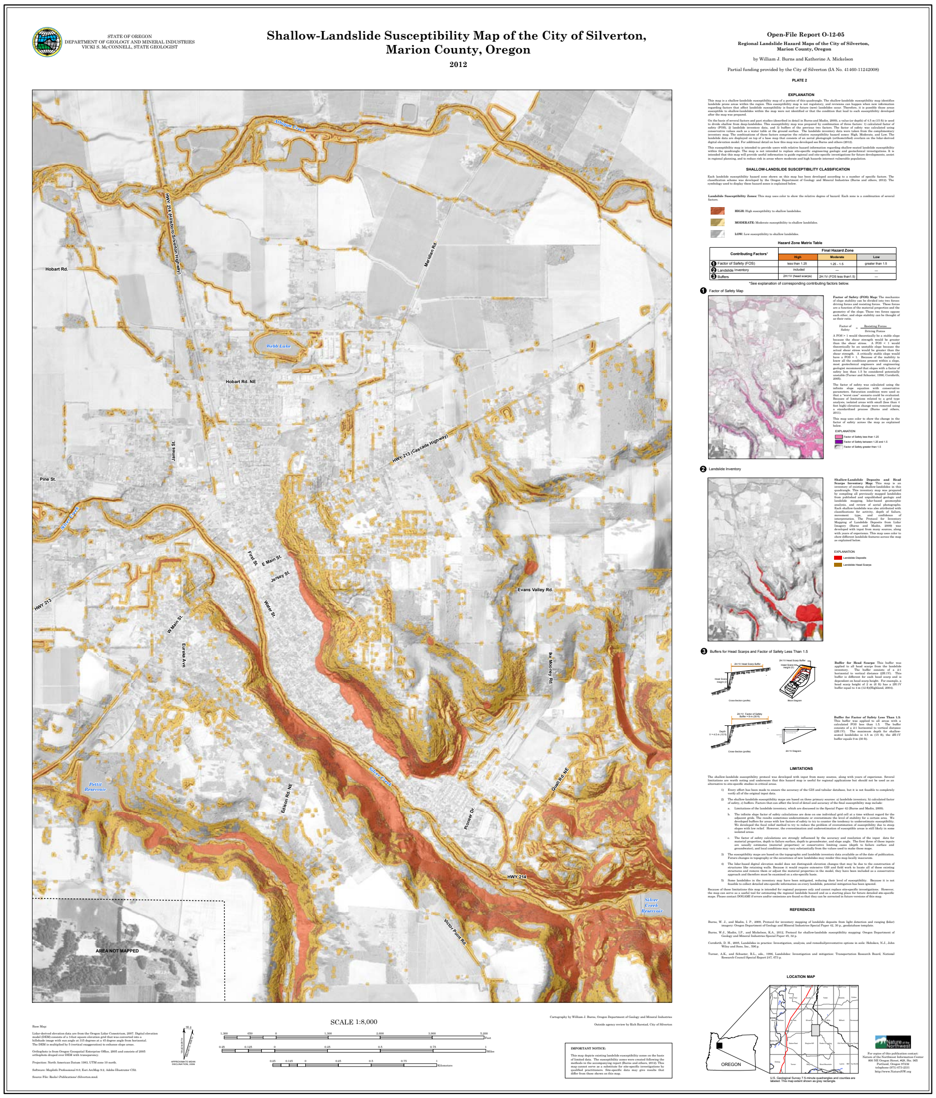


Figure 11. Shallow-landslide susceptibility map (reduced copy of Plate 2 of this report) of the City of Silverton.

4.3 Deep-Landslide Susceptibility

Using the lidar-based landslide inventory and several other data sets, we created a deep-landslide (depth greater than 15 ft [4.5 m]) susceptibility map using four main components (Burns, 2008):

- deep-landslide inventory
- buffers
- geologic units and slope angles
- combination of the previous three factors into final susceptibility hazard zones

All deep slides, flows, and spreads were queried out of the lidar-based landslide inventory database and were saved to a separate GIS file.

Many deep landslides move repeatedly over hundreds or thousands of years; commonly, the continued movement is through retrogressive failure or progressive upslope failure of the head scarp. To account for this potential upslope hazard, we applied a buffer to all mapped deep-landslide deposits as shown in Figure 12.

Because there are many unknowns involved with regional susceptibility models, we also applied a 2H:1V buffer on all landslide head scarps as shown in Figure 13.

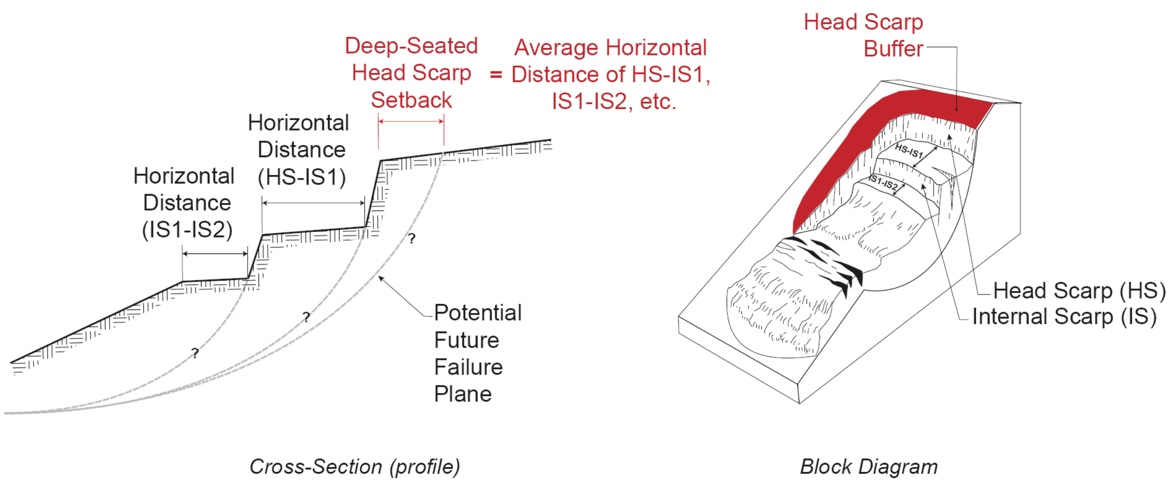


Figure 12. Head scarp retrogression buffer.

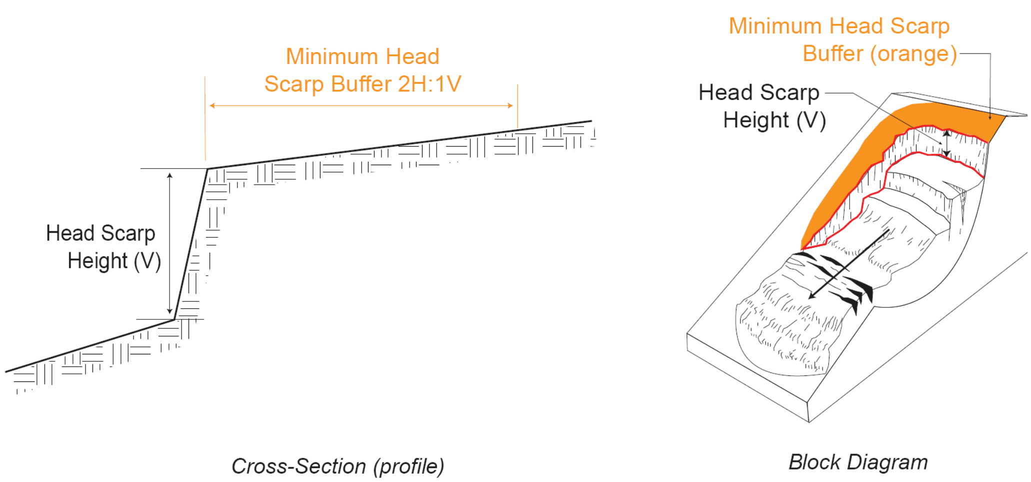


Figure 13. Head scarp buffer.

These two buffers were applied to all head scarps from the deep landslide inventory. In all cases the greater of the two buffers was used.

The last component in the deep susceptibility model is a combination of four factors:

- susceptible geologic units or geologic units that contain identified deep landslides from the inventory
- slope angles greater than 10 degrees
- relative proximity to identified deep landslides from the inventory
- educated judgment of the mapper

First, we set up a generalized geologic map overlain with slopes greater than 10 degrees (Figure 14). These two data sets, along with the other two factors (proximity and judgment), were used to create the boundary between the moderate and low deep-landslide susceptibility zones. A slope angle of 10 degrees was selected on the basis of past mapping of deep landslides using lidar. This map uses color to show different geologic units and slopes across the map.

To create the final deep landslide hazard zones, we combined several of the contributing factors (Table 4).

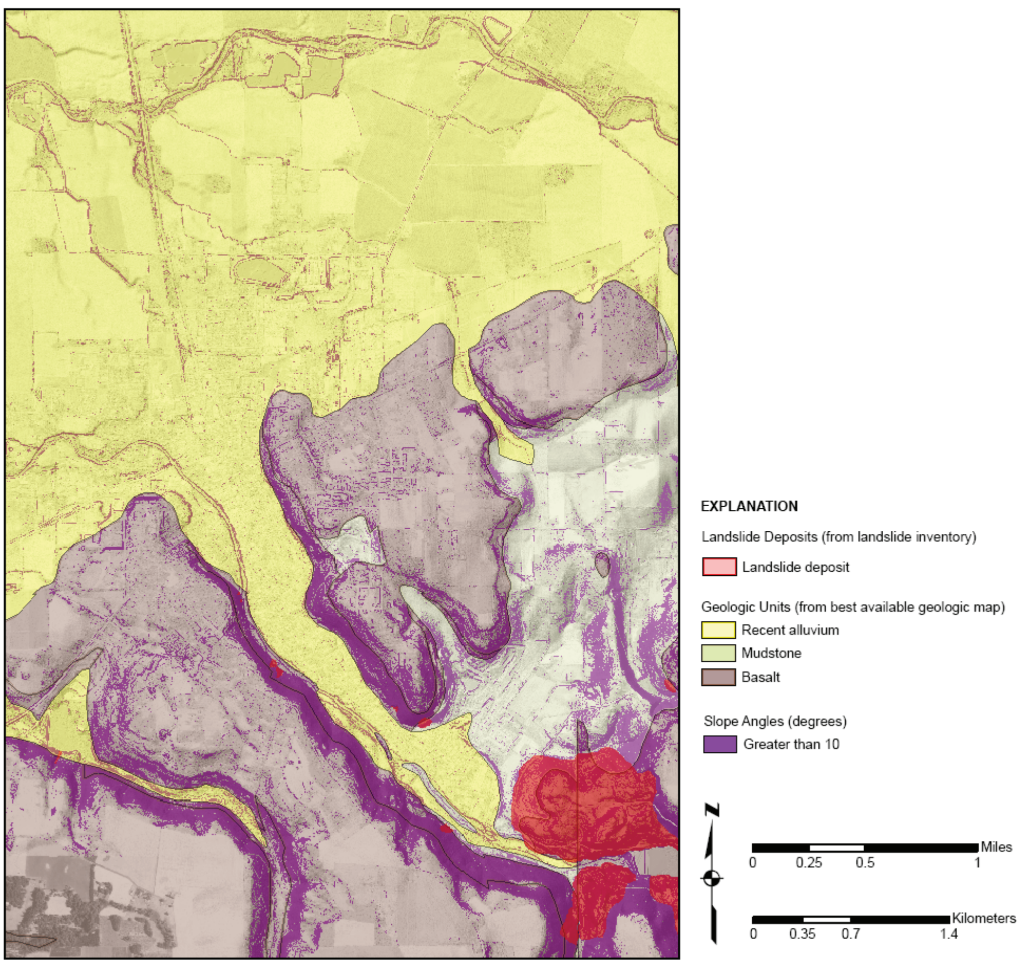


Figure 14. Generalized geologic map of the City of Silverton, overlain with slopes greater than 10 degrees and identified deep landslides.

Table 4. Final hazard zone matrix for deep landslides.

Contributing Factors	Final Hazard Zone		
	High	Moderate	Low
Landslide Inventory	included	—	—
Head Scarp Buffers	included	—	—
Additional Factors	—	included	included

The base deep-landslide susceptibility data (LSdeep-suscept.shp; these GIS files are provided as part of this report) are presented on a 1:8,000-scale map (Plate 3; see reduced copy in Figure 15). This map cannot serve as a substitute for site-specific investigations by qualified practitioners. Site-specific data may give results that differ from those shown on this map. Several other limitations are listed on Plate 3.

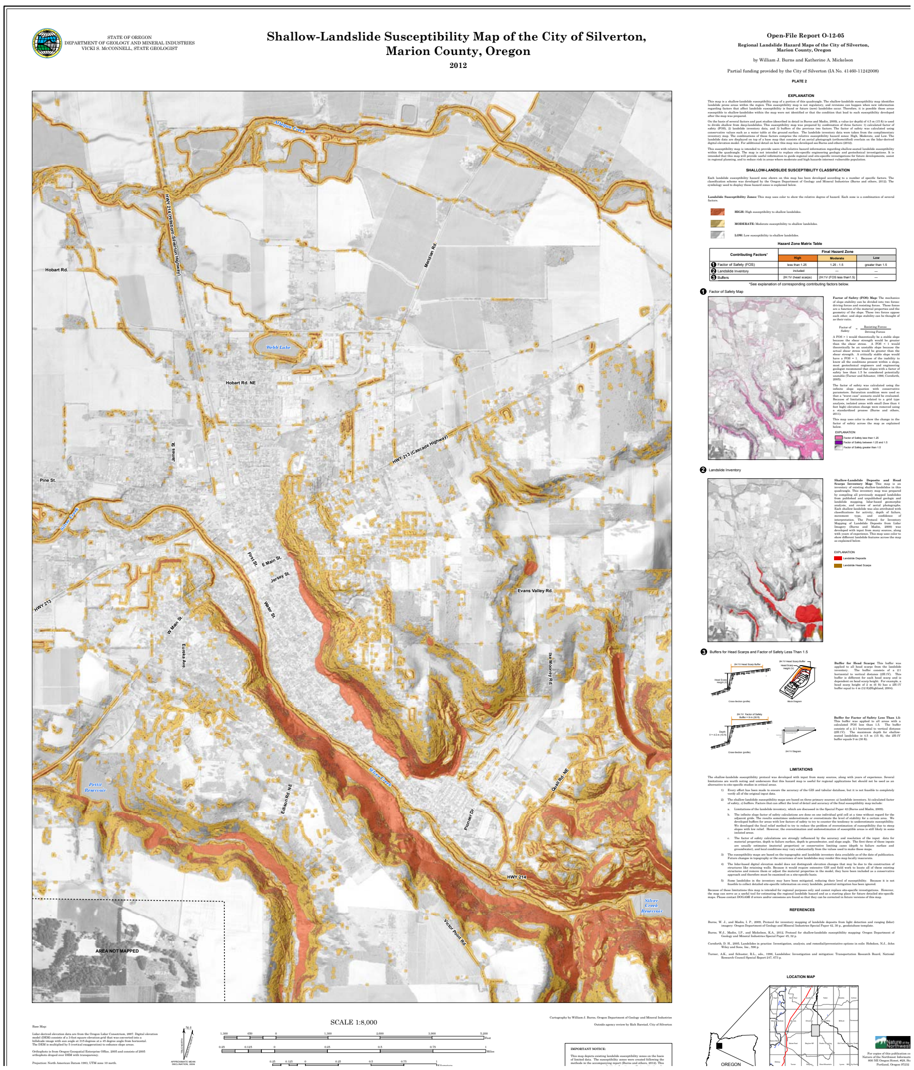


Figure 15. Deep-landslide susceptibility map (reduced copy of Plate 3 of this report) of the City of Silverton.

5.0 RESULTS AND DISCUSSION

We used a lidar-based landslide inventory mapping protocol (Burns and Madin, 2009) to create a landslide inventory of the City of Silverton, Oregon; 110 landslide deposits were located during this project. Of these, 25 are within or directly adjacent to the city. Of these 25, nine were classified as shallow, seven as deep, and two as debris flow deposits. The other seven (of the 25) are areas of rock fall and/or debris slide deposits.

The average prefailure slope angle is 28 degrees. A summary of landslide statistics is provided in Table 5. The average shallow-landslide area is roughly 12,000 ft^2 (1,100 m^2), which is approximately the size of one quarter of a football field. The average deep landslide area is roughly 740,000 ft^2 (68,700 m^2), or approximately the area of 13 football fields. The average depth of failure for the shallow landslides is 7.9 ft (2.4 m), and the average depth of failure for the deep landslides is 41 ft (12.5 m).

Roughly 3% of the City of Silverton is mapped as landslide deposit in the landslide inventory. The most extensive area (in square feet) mapped within or directly adjacent to the city is of the type rock fall and/or debris slide deposit (map symbol RF+DS-T). These deposits are mostly located along the bases of the steep slopes, as shown in Figure 16 and Figure 17, and are likely the result of past shallow debris slides and rock falls initiating along the steep to near-vertical slopes above. Because these deposits are located along the edges of the flat valley floor, many of them already have dense human development. These mapped deposits represent the extent of historic and/or prehistoric events and are not areas identified as having relative susceptibility of future events as in Plate 1 and Plate 2. However, as with most hazards, the past events are a good indication of potential future hazard areas. Therefore risk exposure is considered to be high in these mapped areas.

Table 5. Statistics for landslide areas.

	Area, ft^2	Area, football field
Deep Landslides		
Minimum	2,590	0.05
Maximum	7,686,220	132
Sum	15,559,026	268
Average	740,906	13
Shallow Landslides		
Minimum	340	0.006
Maximum	142,750	2.5
Sum	732,510	13
Average	12,208	0.2

Figure 16. Close-up view of the landslide inventory map in the southern portion of downtown Silverton, Oregon. Rock fall and/or debris slide deposits (RF+DS-T) mantle the base of the steep slope on both sides of Silver Creek (in yellow) See Plate 1 for map symbology..

Figure 17. Photograph of the toe of a mapped rock fall and/or debris slide deposit (RF+DS-T). The average slope angle of these deposits is 10 degrees.

Although Silver Creek Reservoir is located outside city limits, the landslide hazard found in this study combined with the exposure of the reservoir may pose one of the greater risks to the City of Silverton (Figure 18). We mapped both deep and shallow landslides and debris flow deposits along much of the reservoir shore (Figure 18).

The U.S. Army Corps of Engineers maintains a database (National Inventory of Dams; NID) of all dams in the United

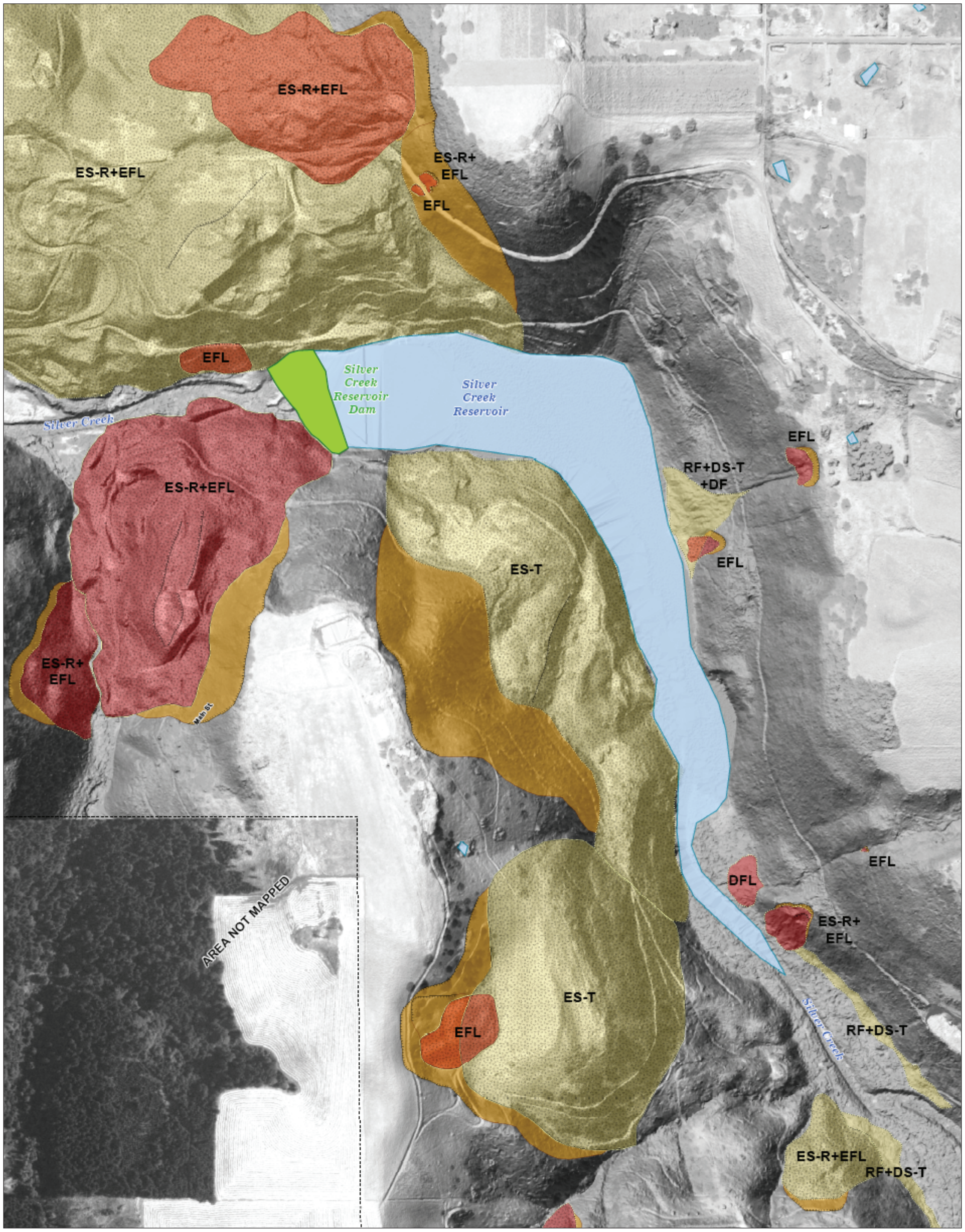


Figure 18. Landslide inventory map of the Silver Creek Reservoir area. The reservoir is located directly up stream of the City of Silverton. See Plate 1 for map symbology.

States that have a high or significant hazard potential or low hazard with certain other criteria such as dam height or storage volume (Goettel and others, 2004). The NID hazard classification is related only to impact if a dam fails, not dam safety level or likelihood of failure. In other words, a “high hazard dam” simply means that people downstream from the dam in the inundation area are at risk. The Silver Creek Reservoir dam is listed as “high” hazard in the NID. The U.S. Army Corps of Engineers tracks hundreds of dams in Oregon because the dams meet certain criteria including significant hazard potential and height. Hundreds of these dams have a high or significant hazard. Again, this hazard is related only to the impact if a dam fails, not to dam safety level or likelihood to fail.

Since 1874, there have been six large-impact dam failures in the United States, and each caused more than 100 deaths. The worst dam failure, in terms of casualties, was the 1889 Johnstown, Pennsylvania, dam failure, which killed over 2,200 people (Frank, 1988).

Two geologic hazards are mainly associated with potential dam failure: landslides and earthquakes. If a landslide moves debris into a reservoir, a local tsunami wave could be generated and could cause the dam to fail or overtop the dam. After dam failure and the related fast drawdown of water in the reservoir, it is very common to have landsliding into the now empty reservoir. Landslides can also directly impact the dam. The Seminary Hill Reservoir dam, located within the City of Centralia, Washington, failed October 5, 1991; the failure was caused by a massive landslide in the siltstone rock formation that underlies the reservoir (Washington State Department of Ecology, Water Resources, 1991).

A major earthquake, either a Cascadia Subduction Zone earthquake or a smaller, crustal or intraplate earthquake, could also cause sufficient damage to the dam or cause landslide movement that could cause damage to the dam and pose a risk of failure. Most dams in Oregon were designed and built in the 1940s to 1960s, when seismic design considerations were significantly lower than they are now (Goettel and others, 2004). The Silver Creek Reservoir was completed in 1975 ,which is just after the first statewide building code was adopted in 1974, but long before the seismic code was updated in the 1980s and 1990s to reflect Cascadia Subduction Zone hazard.

We used the *Protocol for Shallow-Landslide susceptibility Mapping* (Burns and others, 2012) to create a shallow-landslide susceptibility map of the City of Silverton. Approximately 5% of the City of Silverton is classified as highly susceptible to shallow landslides, 19% as moderately susceptible to shallow landslides, and 76% as less susceptible to shallow landslides (Figure 11).

We used a deep-landslide susceptibility mapping protocol (Burns, 2008) to create a deep-landslide susceptibility map of the City of Silverton. Approximately 0.2% of the City of Silverton is classified as highly susceptible, 1% as moderately susceptible, and 99% as less susceptible to deep landslides (Figure 15).

As discussed in Section 4, we developed landslide inventory and shallow-landslide susceptibility maps with the best available data and documented methods; however, several limitations underscore that these maps are designed for regional applications and should not be used as an alternative to site-specific studies in critical areas. These limitations are described in detail on Plates 1–3.

The City of Silverton has a relatively low to moderate landslide hazard, when compared to other communities in Oregon. About one twentieth of the city is underlain by historic and prehistoric landslides. However, some mapped landslide deposits (in particular, rock fall and/or debris slide deposits) are overlain by development. This relationship indicates a significant landslide risk exists in the City of Silverton, and thus there exists a strong need for landslide risk management. Landslides adjacent to Silver Creek Reservoir also indicate a significant landslide risk.

6.0 RECOMMENDATIONS

The maps and GIS databases created as part of this study are intended to provide users with basic information regarding landslides and landslide susceptibility within and near the City of Silverton, Oregon. The maps and GIS databases contain useful information to guide site-specific investigations for future development, to assist in regional planning and development, to mitigate existing landslides and slopes, and to prepare for emergency situations, such as storm events and earthquakes. We reiterate that this information is not appropriate for site-specific evaluations, but it is valuable for regional screening for landslides and selection of appropriate areas on which to focus site-specific studies.

The maps and GIS databases are particularly suitable for the activities listed below:

- Public awareness campaigns
- City development regulation-ordinance
- Issuance of building permits or proposed grading permit conditions
- Public works planning and operations
- Environmental and sustainability issues
- Regional risk-reduction planning and activities
- Neighborhood-scale risk-reduction activities
- Avoidance of very high hazard areas
- Emergency management
- Buyouts in very high or life threatening hazard areas

A particularly valuable use of these maps and this report is as an aid in emergency management activities such as the development and refinement of emergency response plans, public outreach activities, selection of appropriate safe-haven sites, hazard response drills, and estimation of resource impacts for various hazard scenarios (Spangle Associates, 1998). A good example of a potential project would be to evaluate the landslide risk associated with Silver Creek Reservoir and to develop a pre-disaster mitigation plan, including evacuation routes, response drills, landslide monitoring, and/or possible mitigation of the hazard and/or dam.

Another common application of the study in the realm of land use planning, zoning, and regulations is as input to comprehensive planning and the development or upgrade of an existing landslide hazard regulation and/or ordinances. A good example of the use of DOGAMI landslide hazard maps and regulation can be seen in the City of Salem (2012) building code landslide hazards section. Infrastructure is a general term used to refer to critical transportation and utility infrastructure, including roads and highways, railroads, airports, bridges, overpasses and underpasses, natural gas pipelines, electric lines, and water distribution systems. Many infrastructure systems are characterized by components that are dispersed over broad geographic areas that often require regional (as opposed to site-specific) risk assessments. The hazard maps presented in this report can be useful for estimating potential future damage and pre-disaster mitigation to infrastructure.

While it is usually more cost effective to take steps toward mitigation before development occurs, the reality is that many buildings and infrastructure components were built prior to understanding the hazard. For proposed development, land use planning, zoning, and regulations are the best risk reduction. For areas already developed, a collaborative effort including individual land owners, utility owners, and city, county, state, and federal government maybe required. An example of a collaborative landslide risk reduction program is the Seattle Public Utilities Landslide Awareness and Mitigation Program, started after the winter of devastating landslides of 1996-1997. As part of this program, the Seattle Landslide Study (Shannon and Wilson, Inc., 2000) was created. This report includes detailed recommendations for landslide risk reduction, including controlling surface water, groundwater, retaining structures, soil reinforcement, grading, catchment-diversion structures, and vegetation.

One important landslide risk reduction activity discussed in the Seattle Landslide Study and noted in other landslide studies (for example, Portland, Oregon [Burns and others 1998]) is the control of surface storm water. Storm water runoff improvements are generally the least costly mitigation. An increase in storm water management will result in a decrease in landslide risk.

Critical facilities, including hospital, fire and police stations, emergency centers, and school buildings are particularly important to the community and should be designed or mitigated to withstand landslide hazards.

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