APPENDIX C. SUPPLEMENTARY MATERIAL FOR CREATING DEEP LANDSLIDE SUSCEPTIBILITY DATA

Appendix C consists of:

I. Deep landslide susceptibility mapping method; 14 pages extracted DOGAMI Open-File Report O-13-08, Landslide hazard and risk study of northwestern Clackamas County, Oregon (Burns and others, 2013)
—See the digital publication folder for this PDF.

II. Deep landslide susceptibility: Geographic Information System (GIS) method
—The results are shown below and are provided as a PDF in the digital publication folder.

III. Raw results of the deep landslide susceptibility analysis for Bull Run Watershed
—The method is shown below and is provided as a PDF in the digital publication folder.

II. Deep-Landslide Susceptibility: Geographic Information System (GIS) Method

The method we used to identify areas of susceptibility to deep landslides combines several factors, most of which are from or are derived from the deep landslides identified and extracted from the data in SP-42 inventory (Burns and Madin, 2009). Each of the factors is assigned a relative score value and then the factors combined into a final dataset, which is used to assign areas of low, moderate, and high susceptibility. The contributing factors are:

High Susceptibility Zone:
- landslide deposits
- head scarp-flank polygons
- head scarp-flank polygon buffers

Moderate Susceptibility Zone:
- susceptible geologic units
- susceptible geologic contacts
- susceptible slope angles for each engineering geology unit polygon
- susceptible direction of movement for each engineering geology unit polygon

Low Susceptibility Zone
The low susceptibility zone consists of areas that are neither high nor moderate.

The method to identify areas of susceptibility to deep landslides is as follows.

Create an Esri® File Geodatabase

1. Create a new file geodatabase with the following feature datasets:

- A_Landslide_Deposits
- B_Head_Scarp_Flanks
- D_Geologic_Units
- C_Geologic_Contacts
- E_Slopes
- F_Directions

2. Extract all deep landslide deposits from the landslide inventory, name Deep_Landslide_Deposits, and save into the A_Landslide_Deposits feature dataset. Delete extra fields from Deep_Landslide_Deposits.
3. Extract all deep landslide head scarp-flank polygons from the landslide inventory deposits, name Head_Scarp-Flanks, and save into the B_Head_Scarp_Flanks feature dataset.
4. Start with the best available geology map. Combine the units into like engineering geology units. Add text field "general_g" and assign the new generalized engineering geology unit names, for example "Coarse Alluvium". Clip to study extent. Delete all the extra fields, name Engineering_Geology, and save into the C_Geologic_Units feature dataset. Add a field called Polygon_ID to the Engineering_Geology.
5. Compute a slope map from the lidar-derived bare-earth DEM using the Slope tool and name Slope.img.
6. Compute an aspect map from the bare-earth DEM using the Aspect tool and name Aspect.img.

Define the High Susceptibility Zone

Landslide deposits factor

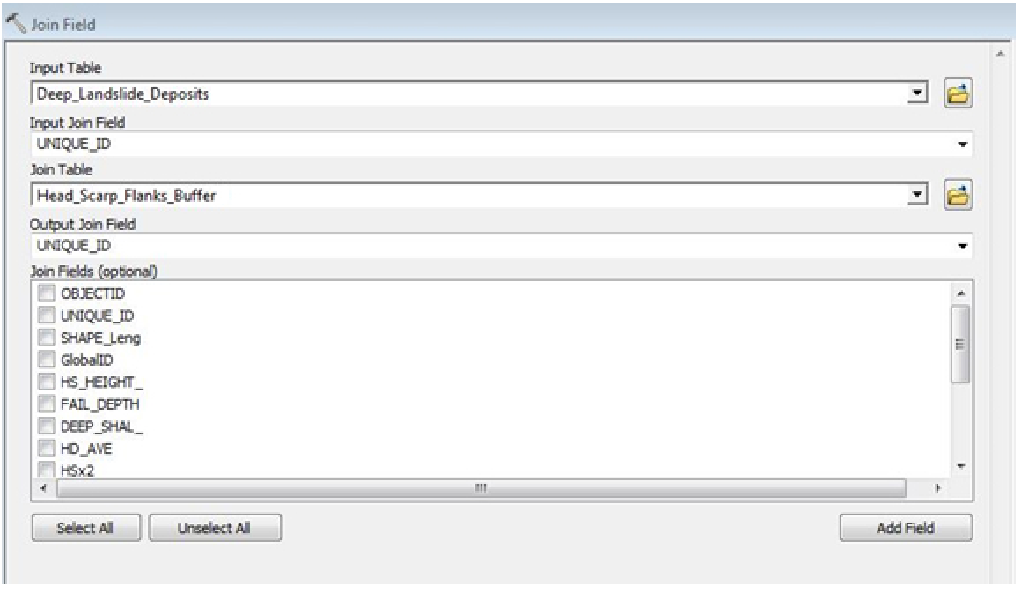
1. Add two fields to Deep_Landslide_Deposits: Relative (text field, 25) and Relat_Susc (short integer), and assign all landslides Relative = "High" and a Relat_Susc = 3.
2. Convert the polygons to raster using the Feature to Raster tool with the field = Relat_Susc and the cell size = 3. Save the raster into the geodatabase and name High_deposits (values = 0, 3, where 3 = high final deep susceptibility zone).

Head scarp-flank polygons and buffers factors

1. In Head_Scarp_Flanks, add two fields: HSx2 (short integer) and Buffer (short integer). Attribute the HSx2 field with HS_HEIGHT field × 2. Attribute the Buffer field with the larger value from either the HD_AVE or the HS_HEIGHT field.
2. Create the buffered file using the Buffer tool with the Head_Scarp_Flanks file, with field set to the Buffer, side type = full and dissolve type = none. Name the output file Head_Scarp_Flanks_Buffer. Add two fields: Relative (text field, 25) and Relat_Susc (short integer) to the Head_Scarp_Flanks_Buffer, then save it in the B_Head_Scarp_Flank feature dataset. Assign all buffered head scarps Relative = "high" and Relat_Susc = 3.
3. Convert the polygons to raster using the Feature to Raster tool with the field = Relat_Susc and the cell size = 3. Save the raster into the geodatabase and name High_HSBuffer (values = 0, 3, where 3 = high final deep susceptibility zone).

Define the Moderate Susceptibility Zone

1. Create a moderate buffer zone around the buffered head scarps and landslide deposits. Use the Join Field tool to join the "Buffer" field from Head_Scarp_Flanks_Buffer to the Deep_Landslide_Deposits.



2. Export the Deep_Landslide_Deposits and name the output Moderate_buffer. Copy all the features from the Head_Scarp_Flanks_Buffer into Moderate_buffer.

3. Use the Buffer tool with the Moderate_buffer file, with field set to the Buffer, side type = full, and dissolve type = all. Name the output file Moderate_zone. Add two fields: Relative (text field, 25) and Relat_Susc (short integer), to the Moderate_zone and save it in the geodatabase. Assign Relative = "moderate" and Relat_Susc = 2.

The moderate susceptibility zone is created through the combination of four factors. These factors are used to determine the boundary between the moderate and low susceptibility zones. The four factors are:

- susceptible geologic units
- susceptible geologic contacts
- susceptible slope angles for each engineering geology unit polygon
- susceptible direction of movement for each engineering geology unit polygon

These four factors will be turned into four raster datasets with scores ranging from 0 to 2 and then added together to create a final moderate zone factors layer.

Susceptible geologic units factor

1. Save the Engineering_Geology file and the Deep Landslide Deposits into the C_Geologic_Units feature dataset and name them Engineering_Geology1 and Deep_Landslide_geolpoly.

2. Create a new field called "Polygon_ID" in the Engineering_Geology file and give every different unit a unique number (1, 2, 3, …). Make sure the Engineering_Geology file is "exploded," as merged units will affect the spatial join.

3. Use the Feature to Point tool to turn the landslides into singular points. Save the points as Deep_landslide_ points.

4. Spatial Join the Engineering_Geology1 to the Deep_landslide points:
   - Target = Deep_landslide points
   - Join = Engineering_Geology1
   - Output = Deep Landslide Deposit_Geolpts
   - Join operation = one to one
   - Keep all target = no
   - Match option = Closest

5. Review that the correct engineering geology has been associated with each point. Make edits to the associated geology if necessary.

6. Use the Join Field tool to join the "Polygon_ID" field from the Deep_landslide points to Deep_Landslide_ geolpoly based on the Unique_ID field. Merge the Deep_Landslide_geopoly to remove overlapping landslide polygons and save as Deep_Landslide_geopolys_merge. Intersect the Deep_Landslide_geopolys_merge and the combined (merged) Engineering_Geology. Save file as Deep_Landslide_Deposit_Geolpoly_intersect

7. Use the Export to Dbase tool and save Deep Landslide Deposit_Geolpoly_intersect in the folder (the export will not save in the geodatabase). Save the file as an Excel® format table. In the Excel file, create a new worksheet and copy the two columns of area data into the worksheet. In the new worksheet, calculate the landslide area/unit area, then convert to percent as shown below.

Engineering Geology Unit Area (miles 2)	Landslide Area Per Unit (miles 2)	Landslide Area / Unit Area (%)
69.01	0.65	0.94%
1.13	0.00	0.04%
36.37	1.27	3.49%
2.81	0.12	4.27%
45.98	2.35	5.11%
20.46	0.26	1.27%
5.95	0.40	6.72%
38.43	5.42	14.10%
0.93	0.00	0.11%
64.73	1.42	2.19%
30.46	11.79	38.71%

8. In Excel®, run the Data Analysis Descriptive Statistics tool on the landslide area/unit area percent. Find the mean and standard deviation.

9. In Esri® ArcMap™, add one field: Score (short integer) to the Engineering Geology1. Assign all units greater than or equal to mean + 1STD a Score = 2 and assign all units less than mean + 1STD and greater than or equal to mean a Score = 1.

10. Convert the polygons to raster using the Feature to Raster tool with the field = Score and the cell size = 3. Save the raster into the geodatabase and name Geology (values = 0, 1, 2).

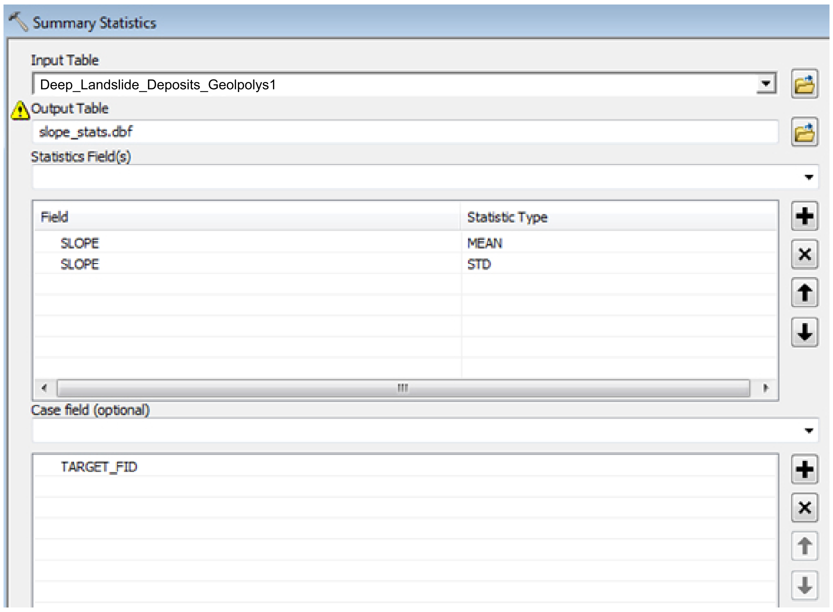
Susceptible geologic contacts factor

1. Use Engineering_Geology to select two units with slides located along their contact (example: Boring Lava and Troutdale fine). Export output each to two different shapefiles and save into C_Geologic_Contacts. Run the Intersect tool with the two units (two files) as the two input features. Output type = line. Save the file as, for example, boring_troutdale_fine_intersect.
2. By using the Select By Location tool with the relationship "are within a distance of the source feature," select all deep slides from the Landslide Inventory Deep Map file that touch the new line file and apply a search distance of 100 ft. Export the selected slides to a new feature class and name it boring_troutdale_fine_ls. Run the Minimum Bounding Geometry tool on this file with geometry type = rectangle by width and name boring_troutdale_fine_rectangle. Examine the new field called MBG_width and find the mean and the standard deviation using statistics.
3. Make a ring buffer using the Ring Buffer tool on the boring_troutdale_fine_intersect file of the mean MBG_width and the mean +1 STD MBG_width as the two buffers and name file boring_troutdale_fine_buffer. Add one field: Score (short integer) to the boring_troutdale_fine_buffer, and save it in the C_Geologic_Contacts feature dataset. Assign all mean buffers Score = 2 and mean + 1STD Score = 1.
4. Repeat for all susceptible contacts. Then merge all buffers to a single file and name Susceptible_Geologic_Contacts.
   Note: If contacts overlap in Susceptible_Geologic_Contacts, merge all Score = 1 and all Score = 2 in the Score field.
5. Select all Score = 2 and use the Clip tool in the Editor toolbar to clip all Score = 1 out from underneath.
6. Add a polygon of the study area boundary to Susceptible_Geologic_Contacts and assign the boundary a score of 0. Clip the 1s and 2s from the boundary.
7. Convert the polygons to raster using the Feature to Raster tool with the field = Score and the cell size =3 ft. Save the raster into the geodatabase and name Contacts.

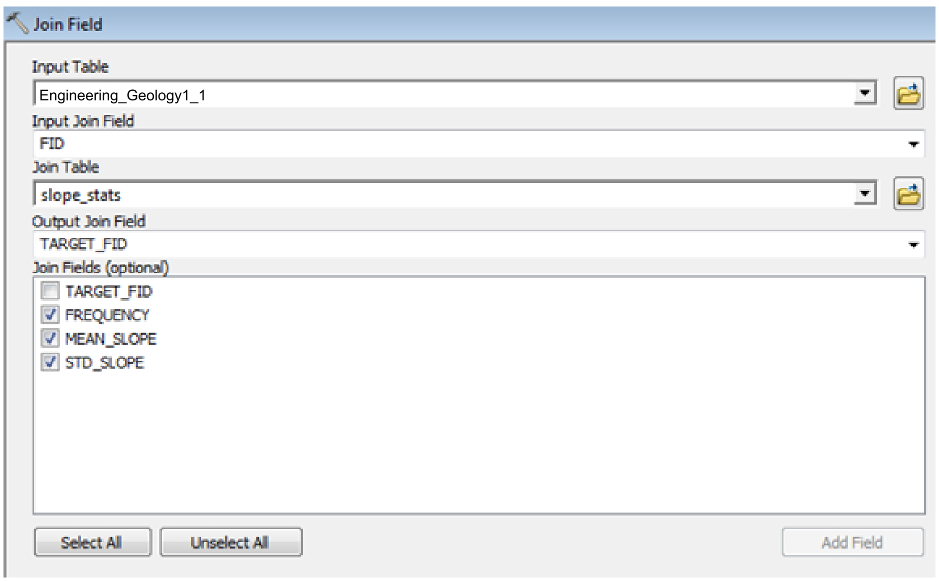
Susceptible slope angles for each engineering geology unit polygon factor

1. Copy and paste the Deep_Landslide_Deposits_Geolpolys1 and Engineering_Geology1 (from C_Geologic_Units) into E_Slopes.

2. Run the Summary Statistics tool on the joined file Deep_Landslide_Deposits_Geolpolys1:
   - Output table: slope stats.dbf
   - Slope = Mean
   - Slope = STD
   - Case Field = Polygon_ID



3. Join field slope stats.dbf to Engineering_Geology1_1 using the Polygon_ID field.



4. Add a field called Mean_2STD to Engineering_Geology1_1. Use the Field Calculator to calculate and populate that field with the Mean field minus 2 STDs.

5. Convert Engineering_Geology1_1 to a raster using the Feature to Raster tool. Field is Slope Mean = value. Output cell size is 3 ft. Output Raster is Slope_Mean (0-90).

6. Use the Raster Calculator with equation Slope => Slope Mean. Output raster is Slope_High (0,1). Use Reclassify to turn the value = 1 to value = 2 and leave value = 0; output raster = Slope_Highr.

7. Convert Engineering_Geology1_1 to a raster using the Feature to Raster tool. Field is Mean_2STD = value. Output cell size is 3 ft. Output Raster is Slope_Mean2S (0-90).

8. Use the Raster Calculator with equation (Slope < Slope_Mean) and (Slope > Slope_Mean2S). Output raster is Slope_Mod (0,1).

9. Use the Raster Calculator tool with equation Slope_Mod + Slope_Highr. Raster dataset name with extension = slope_mod_high.

10. Reclass no data values to zero and name the file Slopes.

Susceptible direction of movement for each engineering geology unit polygon factor

1. Copy and paste the Deep_Landslide_Deposits_Geolpolys1 into F_Direction.

2. Run the Minimum Bounding Geometry tool on Deep_Landslide_Deposits_Geolpolys1 with geometry type = rectangle by width; add the geometry characteristics as attributes to output and name Deep_Landslide_Deposits_Geolpolys1 _Rectangle.

3. Run Summary Statistics to get mean MBG_width.

4. Convert Deep_Landslide_Deposits_Geolpolys1 to a raster using the Feature to Raster tool with 3-ft cell size and the direction as the value; name the raster Landslide_dir.

5. Convert the raster cells to points using the Raster to Points tool with value and name Landslide_Dir_points.

6. Run IDW interpolation tool on the points:
   - Z value field = grid
   - Output raster = Direction_IDW
   - Power = 2
   - Search Radius = Variable
   - Number of Points = blank
   - Maximum Distance = MBG_Width mean
   - Input Barrier = Blank

   Note: If polygons in IDW_Direction raster are cut, place the extra points outside of study area.

7. Use the Raster Calculator to select all values with 360 from the IDW_Direction file and save as IDW_Direction360. Use the Reclassify tool to turn value = 0 to No Data and leave value = 1. Output raster is IDW_Direction360r.

8. Use the Raster Calculator with equation (Aspect =< 22.5) and IDW_Direction360r. Output raster is Dir_High_360. Use the Reclassify tool to turn value = 1 to value = 2 and value=0 to No Data. Output raster = Dir_Highr_360.

9. Use the Raster Calculator with equation (Aspect =< 45) and IDW_Direction360r. Output raster is Dir_Mod_360. Use the Reclassify tool to turn value = 0 to No Data and leave value = 1. Name the output raster Dir_Modr_360.

10. Use the Raster Calculator to select all values with 337.5 from the IDW_Direction file and save as IDW_Direction3375. Use the Reclassify tool to turn value = 0 to No Data. Name the output raster IDW_Direction3375r.

11. Use the Raster Calculator with equation (Aspect =< 22.5) & IDW_Direction3375r. Output raster is Dir_Mod_3375. Use Reclassify value = 0 to No Data and leave value = 1. Name the output raster Dir_Modr_3375.

12. Use the Mosaic to New Raster tool with raster files listed in the following order:
    - Dir_Highr_360
    - Dir_Modr_360
    - Dir_Modr_3375

13. Change Mosaic Operator to FIRST. Raster dataset name with extension = mod_high_3603375 (1, 2).

14. Use the Raster Calculator with equation (Aspect =< (IDW_Direction + 22.5)) and (Aspect => ((DW_Direction – 22.5)). Output raster is Dir_High. Use the Reclassify tool to turn value = 1 to value = 2 and leave value = 0. Name the output raster Dir_Highr.

15. Use the Raster Calculator with equation (Aspect =< (IDW_Direction + 45)) and (Aspect => (IDW_Direction – 45)). Name the output raster Dir_Mod (0, 1).

16. Use the Raster Calculator Dir_Highr + Dir Mod. Output raster is Mod_high (0, 1, 3). Use the Reclassify tool to turn value = 3 to 2. Name the output raster Mod_highr.

17. Use the Mosaic to New Raster tool with raster files listed in the following order:
    - mod_high_360375
    - Mod_highr

18. Change Mosaic Operator to FIRST. Raster dataset name with extension = Direction (0, 1, 2).

19. Use the Reclassify Direction tool to turn value = no data to 0. Output raster is Direction_r.

Final Moderate Zone factors layer

1. Use the Raster Calculator to add Geology + Contacts + Slopes + Direction_r. Name the file Moderate_Factors. The Score field ranges from 0 to 8.

2. Set scores 0–3 with no color. Use values 4–8 as a guide to draw the moderate zone in on the Moderate_zone file created above.

Define the Low Susceptibility Zone

The low susceptibility zone consists of areas that are neither high nor moderate. To determine the low susceptibility zone, clip the study extent area with the high and moderate zone shp file polygons.