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A GIS-BASED TOOLBOX FOR IMPROVED EFFICIENCY AND PRECISION OF LANDSLIDE INVENTORY MAPPING

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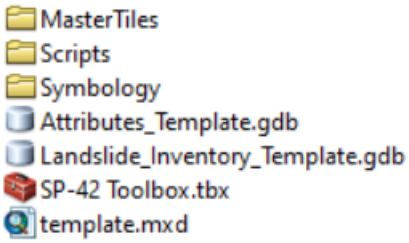
PUBLICATION FOLDER



GEOGRAPHIC INFORMATION SYSTEM (GIS) DATA

See the digital publication folder for files.
Geodatabase is Esri® version 10.1 format. Metadata is embedded in the geodatabase and is also provided as separate .xml format files.

Attributes_Template.gdb:

feature classes:

Age (points)
Confidence (points)
Movement_Class_1 (points)
Movement_Class_2 (points)
Direction (polylines)
Fan_Height (polylines)
Geology_1 (polylines)
Geology_2 (polylines)
HS_Height (polylines)
HS_IS1 (polylines)
IS1_IS2 (polylines)
IS2_IS3 (polylines)
IS3_IS4 (polylines)
LS_Slope (polylines)
Unique_ID (polylines)

Tables:

Movement_Class_1_LUT
Movement_Class_2_LUT

Landslide_Inventory_Template.gdb

feature classes:

Deposits (polygons)
Scarp_Lines (polylines)

1.0 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 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 (Burns and Madin, 2009).

In 2009, the Oregon Department of Geology and Mineral Industries (DOGAMI) published Special Paper 42 (SP-42), "Protocol for Inventory Mapping of Landslide Deposits from Light Detection and Ranging (Lidar) Imagery" (Burns and Madin, 2009), a roadmap developed to create and maintain a consistent landslide inventory for the state of Oregon.

This publication and associated ESRI ArcToolbox, called the SP-42 Toolbox, are designed to assist landslide mapping following the SP-42 method by improving its efficiency and precision. Completing a publication-ready landslide inventory for a study area using the SP-42 Toolbox includes five primary steps:

1. Acquire input data and run the ***SP-42 Part 1 Base Map Setup*** tool.
2. Map the landslide inventory (i.e., identify and delineate landslides).
3. Attribute the landslide inventory (i.e., underlying geology, deep or shallow, etc).
4. Run the ***SP-42 Part 2 Attribute Transfer*** tool and review the outputs.
5. Run the ***SP-42 Part 3 Final Formatting*** tool and review the outputs.

Landslide inventories help Oregon communities become more resilient to the impacts of landslide hazards and the SP-42 Toolbox allows inventories to be developed more efficiently and precisely.

2.0 INTRODUCTION

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 (Burns and Madin, 2009).

In 2009, the Oregon Department of Geology and Mineral Industries (DOGAMI) published Special Paper 42 (SP-42), "Protocol for Inventory Mapping of Landslide Deposits from Light Detection and Ranging (Lidar) Imagery" (Burns and Madin, 2009)[1]. This protocol was developed so that DOGAMI and others can produce consistent, lidar-based landslide inventories for the state of Oregon. DOGAMI has established SP-42 as the standard for the Oregon, and the foundation for geographic information system (GIS)-based landslide inventory through the state Geospatial Enterprise Office Framework program[2]. In addition to landslide inventory maps for specific areas, data published by DOGAMI using this protocol is incorporated into the Statewide Landslide Information Layer for Oregon (SLIDO) (Franczyk and others, 2019).

[1] https://www.oregongeology.org/pubs/sp/p-SP-42.htm

[2] Https://www.oregon.gov/geo/Pages/hazardsframe.aspx

To assist the geologist in producing efficient and precise landslide inventories using the protocol outlined in SP-42, DOGAMI developed the SP-42 Toolbox. This toolbox contains three GIS tools, each written in the Python® computer language, to create and organize landslide inventory data as well as supporting datasets. It also prepares the completed landslide inventory datasets formatting for publication and integration into SLIDO. Using the SP-42 Toolbox to produce a landslide inventory ready for publication consists of five primary steps, which will be discussed in more detail in subsequent sections.

This document is written primarily as a user guide for the SP-42 Toolbox. It provides instructions on installing and running the SP-42 Toolbox, using the current attribution methods, and understanding the tool output datasets. Users of this toolbox should be very knowledgeable about GIS practices and spatial data. They should also be very familiar with creating landslide inventories and the methods described in SP-42. More detailed information on the protocol for creating the landslide inventory should be referenced in the SP-42 report by Burns and Madin (2009).

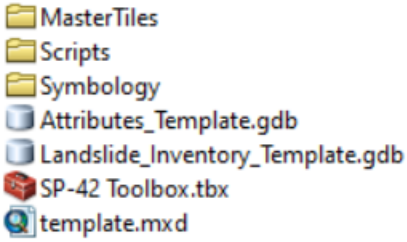
The intended audience of this paper is primarily DOGAMI scientists but also includes government, industry, and university scientists who are interested in producing standardized landslide inventory maps.

3.0 SOFTWARE REQUIREMENTS AND SETUP

The SP-42 Toolbox is a custom toolbox designed at DOGAMI to assist the geologist in mapping, attributing, and publishing a comprehensive landslide dataset following the methods outlined in Special Paper 42 (Burns and Madin, 2009). It is available for the ArcMap® and ArcPro® platforms. The ArcMap® toolbox software requirements include an Esri® ArcGIS® Desktop 10.x Advanced License, with ArcGIS Spatial Analyst extension. The current version of Python 2.x should be installed as part of the ArcGIS® installation. The ArcPro® software requirements include the ArcPro® Advanced License, with the ArcPro® Spatial Analyst extension. To run either toolset, the user does not need knowledge of Python computer language but will need to understand how to add and use toolboxes in ArcGIS. This report details methods based on running the ArcMap version of the SP-42 Toolbox.

The toolbox contains three tools intended to be run in succession during a landslide inventory project. Both the ArcMap and ArcPro versions of the toolset are included with this publication and come in the form of compressed folders, SP42_Toolbox_ArcMAP.zip and SP42_Toolbox_ArcPRO.zip, with the following contents (**Figure 3-1**):

Figure 3-1. A diagram of the downloadable SP-42_Toolbox_ArcMap Folder, which includes the SP-42 Toolbox and necessary data.

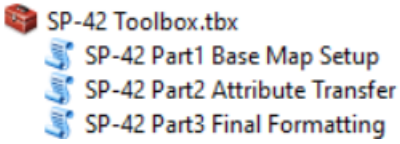


The contents of the SP-42_Toolbox_ArcMap Folder include the following:

1. Attributes_Template.gdb - A geodatabase to store the attributes.
2. Landslide_Inventory_Template.gdb - A geodatabase to store the spatial data (deposits, scarp_flanks, scarps).
3. MasterTiles folder - Contains a polygon shapefile (.shp) of 1/100th USGS 100k quadrangle extents to be used for formatting base map datasets.
4. Symbology folder - Contains symbology layer (.lyr) files for numerous landslide attributes and base map data.
5. Scripts folder – Contains three Python files that correspond to the tools contained in the ArcToolbox.
6. SP-42 Tools toolbox (.tbx)
7. The template.mxd is the ArcMap file template that will be populated based on the project.

It is recommended that the SP-42_Toolbox_ArcMap Folder is copied to your local computer's C: drive. **It is important to note that for the toolset to run properly, do not move or rename any of the files and folders found in the downloaded SP-42 Folder!** After unzipping the SP-42_Toolbox_ArcMap Folder and placing it in the C: drive, open ArcCatalog and add the SP-42 Toolbox through the ArcToolbox Window. More detailed steps for adding custom toolboxes to can be found on the ESRI website[3]. Once the SP-42 Toolbox is loaded into the ArcToolbox tree, it is ready for use. The toolbox and its contents should look like this (**Figure 3-2**):

Figure 3-2. Diagram of the contents of the SP-42 Toolbox.



4.0 METHODS

There are five general steps for using the toolbox, as outlined below. The following sections of this report provide additional details for each step.

1. **Acquire input data and run *SP-42 Part 1 Base Map Setup* tool.** These data include: a project folder location, the study area digital elevation model (DEM), a study area extent polygon, previously mapped landslide deposits and historic points feature classes, and previously mapped geologic map unit polygon features. Run the ***SP-42 Part 1 Base Map Setup*** tool to create and organize base map, attribute, and deposit datasets, within geodatabases as well as create an ArcMap project file (.mxd) populated and symbolized with these data.
2. **Map landslide inventory.** After completing step 1, the geologist maps landslides in the study area using the map (.mxd).
3. **Attribute study area landslide inventory.** After landslide mapping is complete, the geologist attributes and reviews the landslide inventory.

[3]https://desktop.arcgis.com/en/arcmap/latest/analyze/managing-tools-and-toolboxes

4. **Run *SP-42 Part 2 Attribute Transfer* tool and review.** Once landslides have been mapped and attributed, run the ***SP-42 Part2 Attribute Transfer*** tool. This tool will assign attribute information to landslide feature classes. Review the combined spatial and attribute data.
5. **Run the *SP-42 Part3 Final Formatting* tool and review.** This tool will prepare and organize all final landslide inventory datasets for publication and integration into SLIDO.

4.2 Step 1: Acquire Input Data and Run SP-42 Part 1 Base Map Setup Tool

Begin a new landslide inventory project by running ***SP-42 Part1 Base Map Setup*** (Figure 4-1). The purpose of this tool is to populate a project folder with a formatted .mxd and all the datasets needed for the geologist to identify landslide areas.

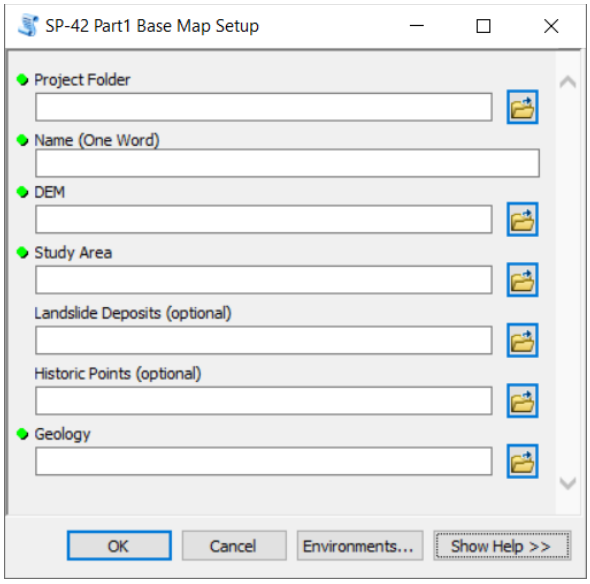
Helpful Hints:

- The toolbox can be added through the Toolbox Window in ArcMap or can be accessed in ArcCatalog table of contents.
- Running the tools while accessing the data through ArcMap or ArcCatalog may cause errors due to data locks.

There are seven inputs to the ***SP-42 Part 1 Base Map Setup*** tool. These are a project folder location, a DEM raster that covers the project study area, a polygon feature class of the study area, a polygon feature class of previously mapped landslide deposits, a point feature class of previously mapped historic landslide sites, and a polygon feature class of the geology. The DEM should be a lidar-derived raster with a resolution of 3-feet, as required for SP-42 methods (Burns and Madin, 2009). The geology polygon feature class must contain a text field called "MapUnits" of a length of no more than 50. The following section will provide additional descriptions of the input data.

Once the input datasets are prepared, run the ***SP-42 Part 1 Base Map Setup*** tool. The tool will provide an explanation of each input by clicking on the [Show Help >>] button.

Figure 4-1. The SP-42 Part 1 Base Map Setup tool user interface.

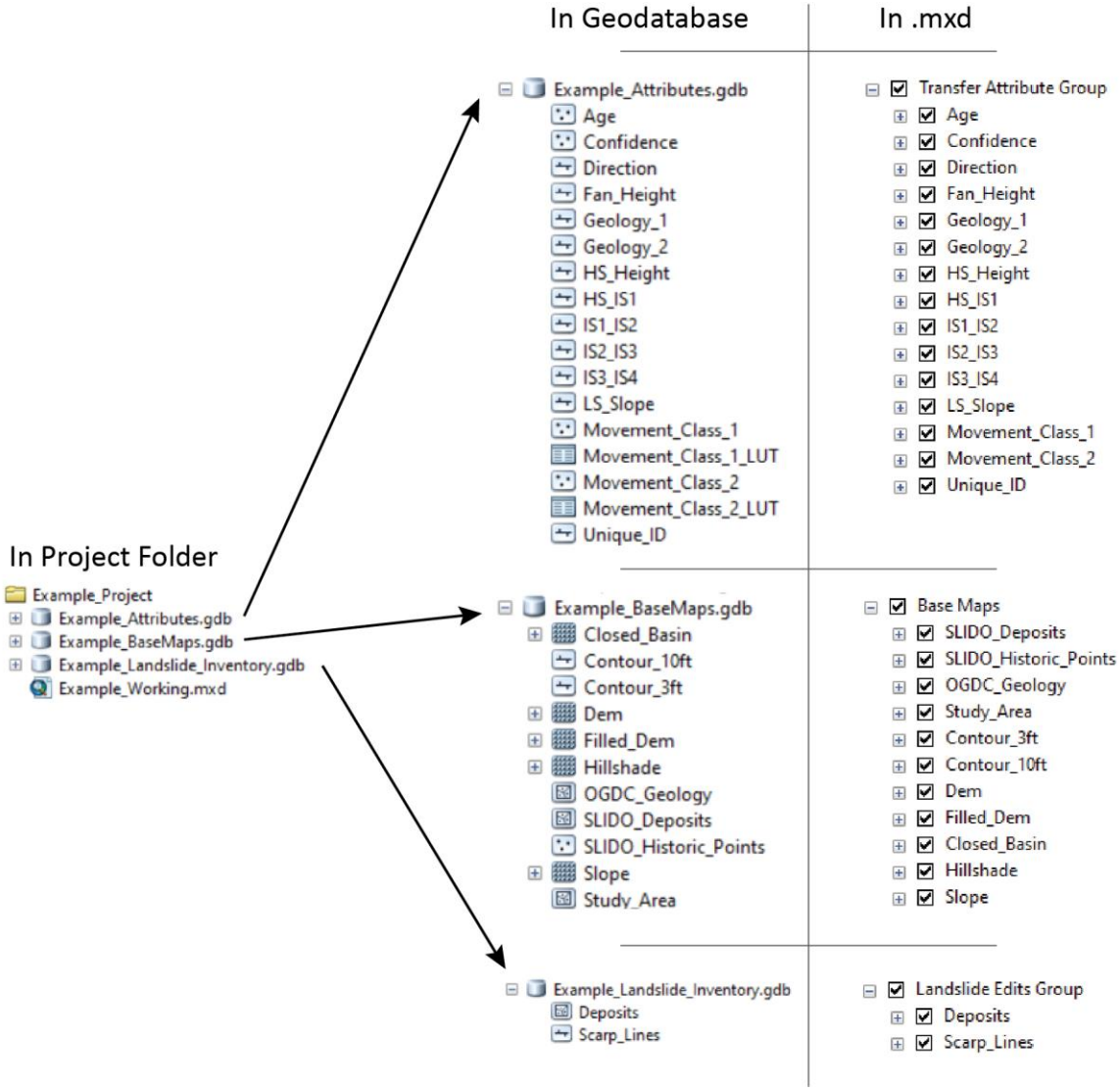


Descriptions of each input in the toolbox are as follows:

1. **Project Folder:** User-created folder location where tool outputs will be created.
2. **Name (One Word):** User-created unique project title. Term should contain no spaces; consider using capital letters and/or dashes to create a multi-word title (e.g., "SmithCounty" or "Smith-County"). This term will be appended to the beginning of the name of each output geodatabase and the .mxd.
3. **DEM:** The "DEM" input is the digital elevation model (DEM) raster that covers your study area polygon. This dataset sets the projection for all outputs. It will be clipped to the study area polygon.
4. **Study Area:** The "Study Area" input is the polygon feature class representing the project study area.
5. **Landslide Deposits (optional):** The "Landslide Deposits" input is the location of the polygon feature class of existing mapped landslide deposits. It will be clipped to the study area.
6. **Historic Points (optional):** The "Historic Points" input is the location of the point feature class of existing mapped historic landslide initiation sites. It will be clipped to the study area.
7. **Geology:** The "Geology" input is the location of the polygon feature class of mapped geology. It will be clipped to the study area.

Running this tool will create the following within the project folder: (1) a geodatabase containing base map data that will be used by the geologist to map landslide deposits, (2) a geodatabase containing attribute feature classes, (3) a geodatabase containing landslide inventory deposit and scarp line feature classes, and (4) an .mxd containing the symbolized base maps, attribute feature classes, and deposits and scarp lines feature classes (**Figure 4-2**). Refer to the SP-42 report for a comprehensive list of base map and attribute datasets.

Figure 4-2. Example of Part 1 tool outputs with project name "Example". The "In Project Folder" column includes the Example_Project folder containing three geodatabases and one .mxd. The "In Geodatabase" column shows the *SP-42 Part 1 Base Map Setup* tool outputs within each geodatabase. The "In .mxd" column shows the *SP-42 Part 1 Base Map Setup* tool outputs as seen in the table of contents within the .mxd.



The base maps geodatabase includes raster and vector datasets that can be used to assist the geologist in identifying landslides. One example not included in the original SP-42 publication method is the Closed Basins raster. When landslides occur, they can change the surface hydrology, which sometimes results in the creation of closed basins. Some of these closed basins fill with water and are called sag ponds. Some do not contain water but can still be seen with a detailed lidar-based DEM. Over time, if the landslide does not continue to move, these closed basins will disappear through erosion. In addition to assisting the geologist in identifying a landslide deposit, the presence of closed basins contributes to the geologist's assessment of confidence in the deposit (which is an attribute of the landslide inventory).

Once the first tool has been successfully run, the geologist can build the inventory by mapping and attributing landslides (deposits, scarp lines, and scarp flanks) within the project area. Although the mapping and attribution can occur simultaneously, it is recommended that they are performed

sequentially. SP-42 describes how to map and attribute landslide deposits. Herein, we describe how to use the ***SP-42 Part2 Attribute Transfer*** tool to simplify the attribution of each landslide deposit. Additional tips and tricks are provided throughout the next two sections.

4.3 Step 2: Map Landslide Inventory

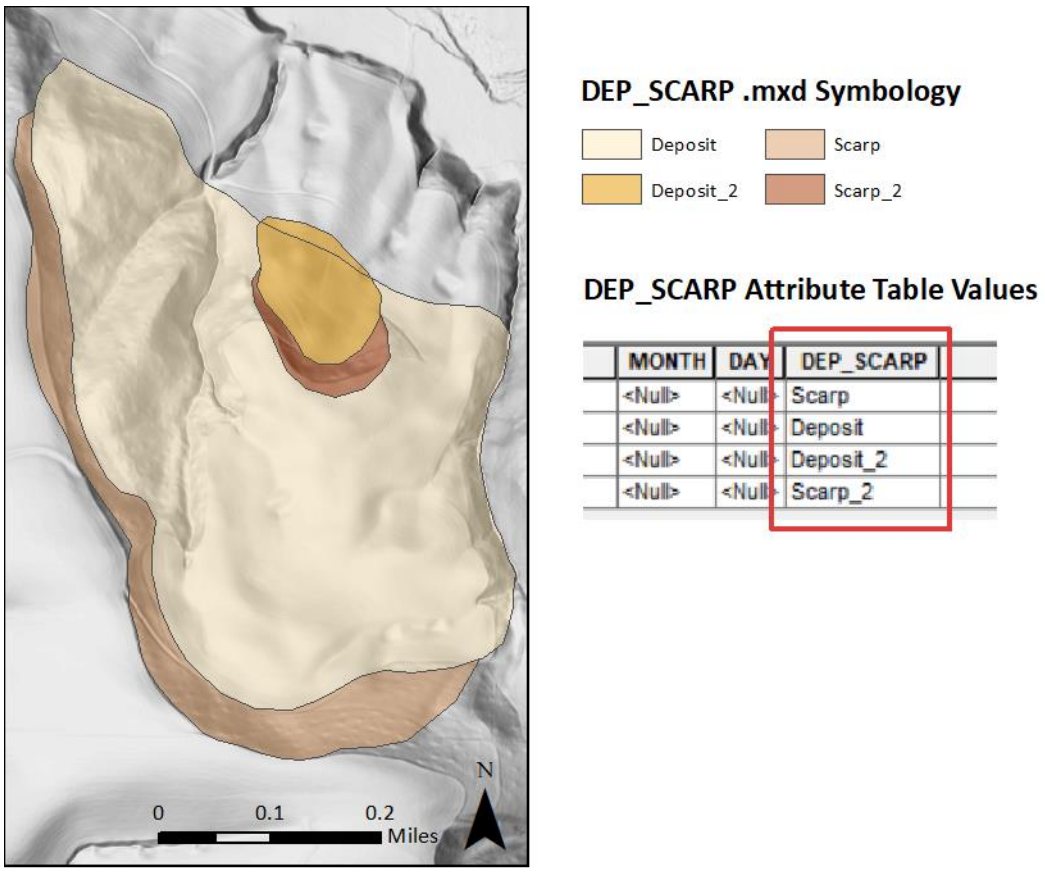
The first step in creating the landslide inventory is to map landslide deposits and scarps. Deposits and scarp flanks are mapped as polygons using the Deposits feature class; internal scarps are mapped as lines using the Scarp_Lines feature class. Both feature classes are in the Landslides_Inventory.gdb geodatabase and found in the 'Landslide Edits Group' in the .mxd table of contents (refer to **Figure 4-2**).

When mapping a landslide, the first decision is whether the feature is a deposit or a scarp flank. The second decision is whether the landslide is a new landslide or one that overlaps another previously mapped landslide. The attribute field that determines the feature type is called 'DEP_SCARP' and can be seen in the Landslide Edits Group > Deposits feature class symbology. When creating a new landslide polygon, it is classified as 'Deposit' or 'Scarp'. Overlapping landslide polygons are classified as 'Deposit_2' or 'Scarp_2' (**Figure 4-3**). During an edit session in the .mxd, the geologist will choose one of these four types, depending on the deposit or scarp flank they are digitizing.

Helpful Hints:

- Map all the geospatial data first (deposits, scarp flanks, and scarp lines).
- After reviewing the inventory, attribute the landslides using the method outlined in the next section (4.4).
- It is more efficient to place and review all attributes for one deposit at a time before moving to the next.

Figure 4-3. Map example of the four Deposit feature class types. The 'Deposit' and 'Scarp' DEP_SCARP attribute field values are assigned to a single, new deposit and scarp flank pair. The 'Deposit_2' and 'Scarp_2' DEP_SCARP attribute field values (red box) are assigned to single deposits and scarp flank pairs that overlap existing landslide pairs .



Scarps are digitized using the Scarp_Lines feature class. Care must be taken to draw the line in the correct direction, however unlike the Deposits feature class, no attributes need to be identified during the mapping process. Additional guidance on delineating landslide features can be found in SP-42. Once all features have been mapped within the study area, we suggest having another geologist review the inventory for accuracy and completeness.

4.4 Step 3: Attribute Study Area Landslide Inventory

The next step is to assign attributes to the landslide polygons, including characteristics like slope, bedrock geology, and direction of movement. Because attributing landslides can be a tedious process when done manually for hundreds of deposits, an automated process was designed wherein the geologist places various features in such a way that the ***SP-42 Part2 Attribute Transfer*** tool can use them to automatically populate the attributes table for each landslide. The following figures (**Figure 4-4, Figure 4-5, Figure 4-6**) illustrate the placement methods of attribtue features for general types of landslides: debris flow fan deposits, rock fall deposits, and then the other common deposit types.

Figure 4-4. An example of attribute feature placement methods for a debris flow fan deposit. Map A shows examples of linear attribute feature type placement and Map B shows examples of point attribute feature type placement.

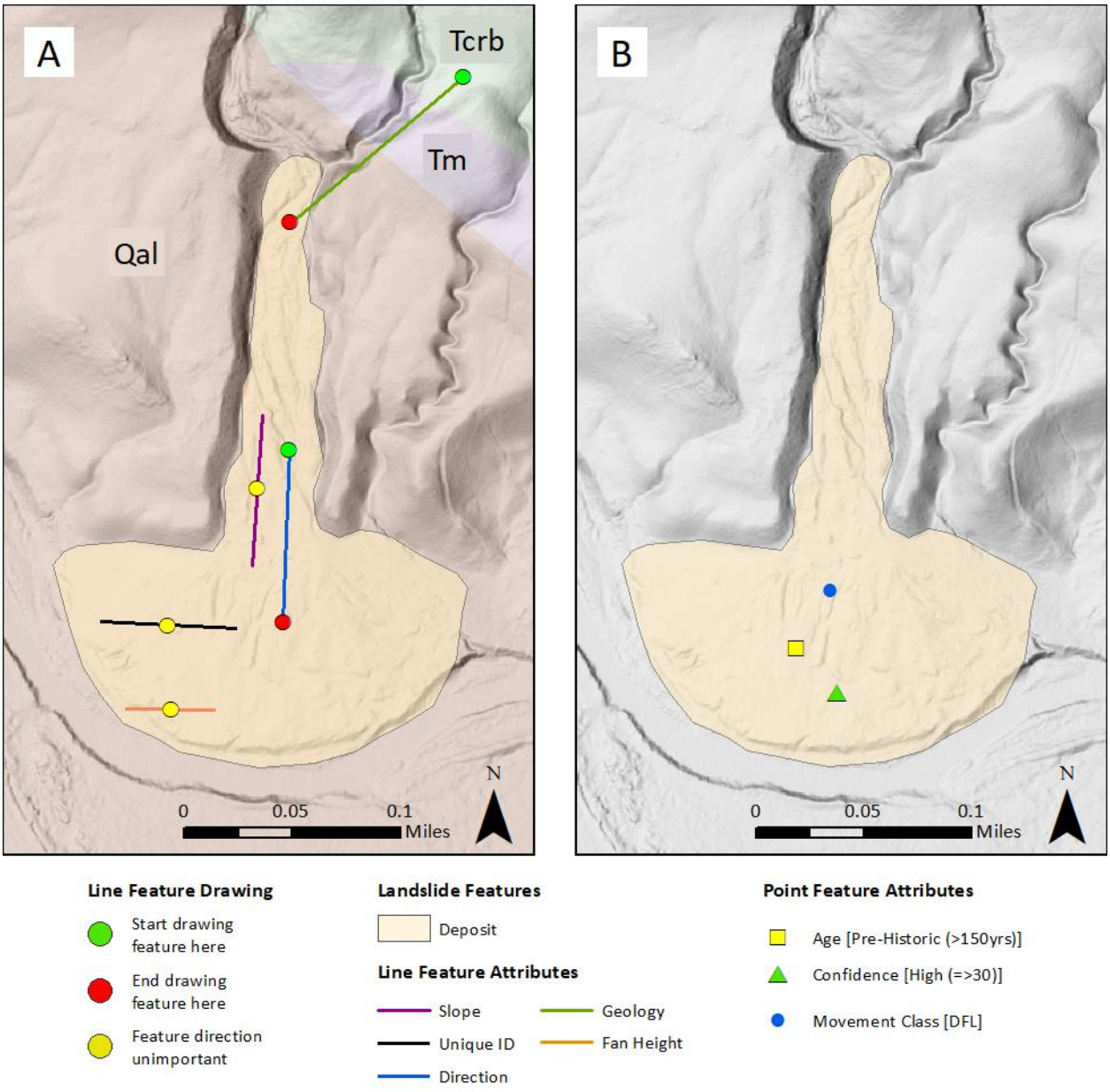


Figure 4-5. An example of attribute feature placement methods for a rock fall deposit. Notice that this landslide type needs the least amount of attribute features. No measurements of direction or slope are necessary for this type of landslide. Map A shows examples of linear attribute feature type placement and Map B shows examples of point attribute feature type placement.

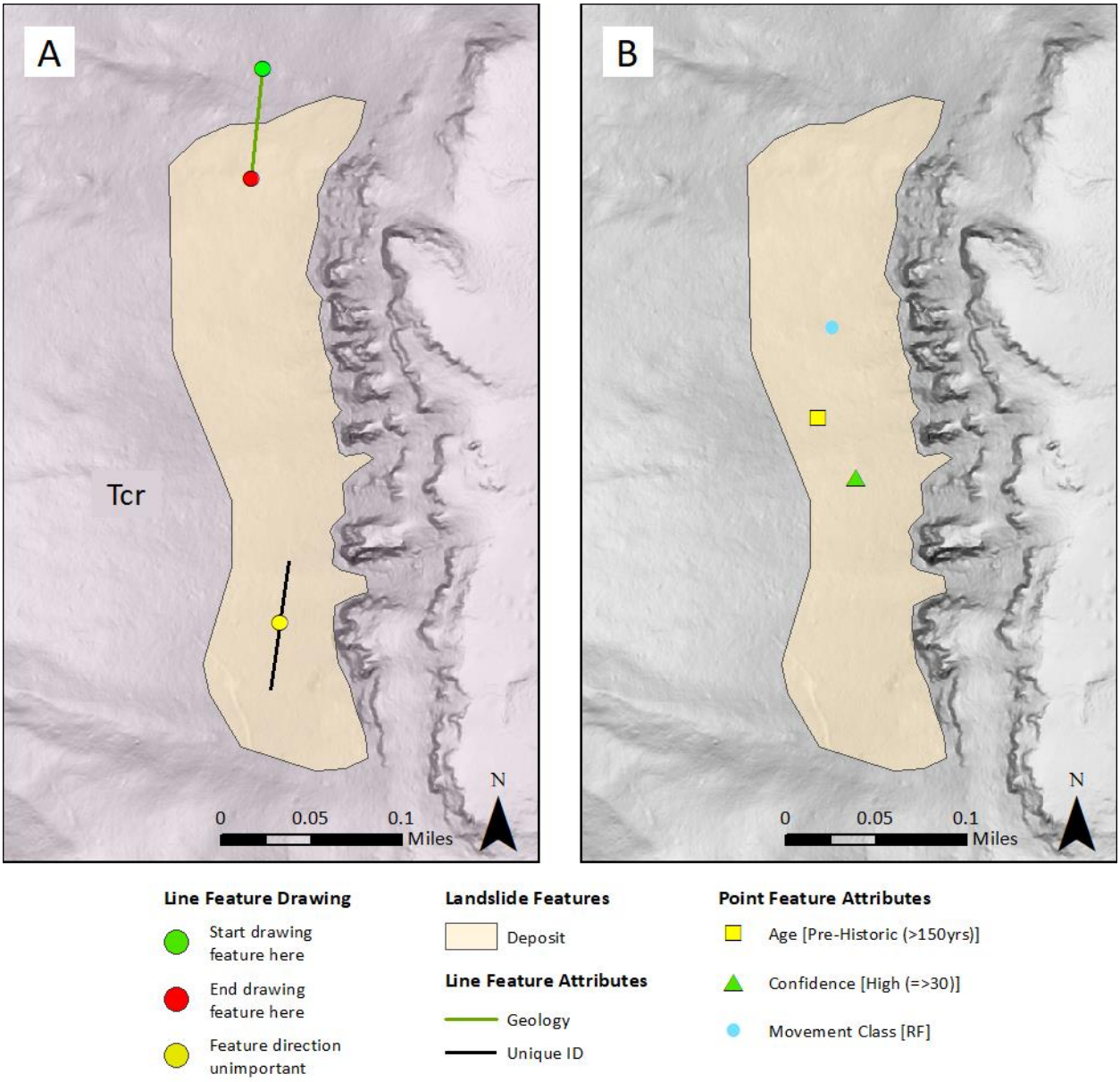
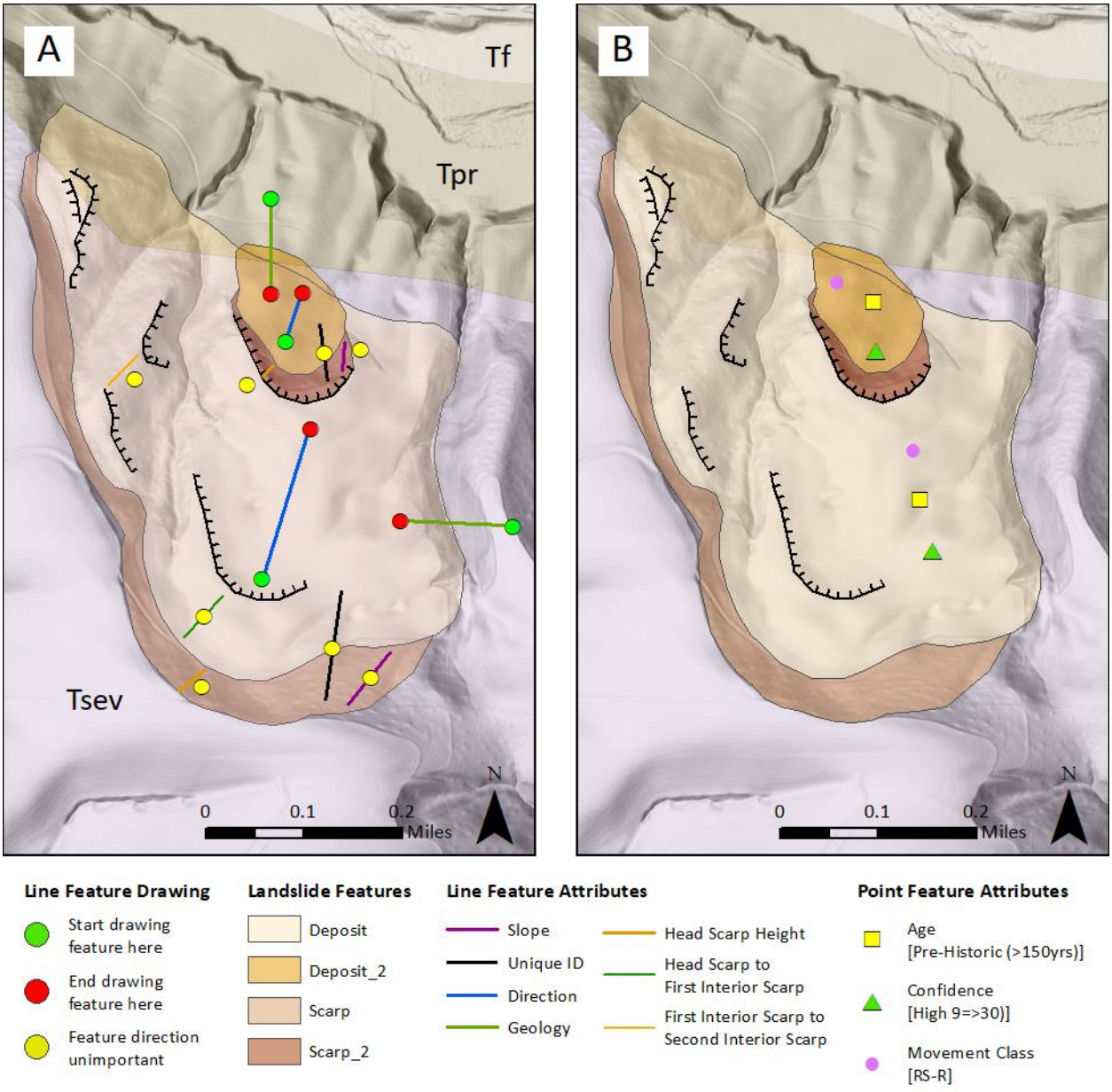


Figure 4-6. An example of attribute feature placement methods for two landslide deposits and their corresponding scarp flanks, with the secondary set (DEP_SCARP field = 'deposit_2' and 'scarp_2') partially on top of the larger set (DEP_SCARP field = 'deposit' and 'scarp'). Because the secondary landslide set of deposit and scarp flank falls on top of the larger deposit and scarp flank, they are assigned the 'deposit_2' and 'scarp_2' values for the DEP_SCARP field. The attribute features are almost all contained within each landslide set and do not overlap with the other landslide set. Map A shows examples of linear attribute feature type placement and Map B shows examples of point attribute feature type placement.



The following sections briefly describes each attribute and how to place the appropriate feature classes to transfer the correct values to the final attributes table. For more information on each attribute, refer to SP-42 (Burns and Madin, 2009).

Table 4-1 provides definitions of each attribute. All attribute feature classes are created and placed within an edit session in the .mxd. Attributes associated with the overall landslide (i.e., age, geology, slope) are always placed within the deposit; others require more careful placement. More information on these details will be provided for each attribute. For the following discussion, any instructions related to a standalone Deposit and Scarp also apply to overlapping landslides (i.e., 'Deposit_2' and 'Scarp_2').

Table 4-1. SP-42 Landslide deposit attribute field names with descriptions and the corresponding attribute feature class type used by the SP-42 Toolbox.

Attribute Type	*Description*	*Type*
Age	Estimated age	Point
Confidence	Confidence of identification	Point
Direction	Landslide direction, in increments of 22.5 degrees	Line
Fan_Height	Change in elevation from the top of the fan to the toe	Line
Geology_1	Assigns primary geology map unit(s) that the landslide overlays	Line
Geology_2	Assigns secondary geology map unit(s) that the landslide overlays	Line
HS_Height	Defines the vertical height of a landslide's scarp flank	Line
HS_IS1	Horizontal distance from head scarp (HS) to internal scarp no. 1 (IS1)	Line
IS1_IS2	Horizontal distance from internal scarp no. 1 (IS1) to internal scarp no. 2 (IS2)	Line
IS2_IS3	Horizontal distance from internal scarp no. 2 (IS2) to internal scarp no. 3 (IS3)	Line
IS3_IS4	Horizontal distance from internal scarp no. 3 (IS3) to internal scarp no. 4 (IS4)	Line
LS_Slope	Adjacent slope angle, 0 – 90 degrees	Line
Movement_Class_1	Primary movement classification	Point
Movement_Class_2	Secondary movement classification	Point
Unique_ID	Unique identification number	Line

4.4.1 Unique ID

The Unique ID attribute assigns a unique identification to individual landslides and relates a deposit to its associated scarp flank. This feature class is a line and **is mandatory for the correct transfer of some of the other attributes.** For any landslide deposit with an associated scarp flank, draw a line starting within the scarp and ending within the deposit. This will pair the associated scarp and deposit by assigning them the same unique ID. (**Figure 4-4, Figure 4-5, Figure 4-6**). Do not allow the line to overlap with any other polygons. For rock falls, debris flow fans, or any other landslide deposit that does not have an associated scarp, draw the entirety of the line within a single deposit. Each deposit polygon should contain a unique ID line whether it has an associated scarp flank or not.

Helpful Hints:

- When drawing this feature for a scarp flank/deposit combination, think: "This scarp flank (click in scarp flank polygon) goes with that deposit (click in associated deposit polygon)!"

4.4.2 Age

The geologist must assign an age of 'historic (<150 years old) or 'pre-historic' (>150 years old) to each deposit. This can now be easily done by selecting one of two symbologies for the point feature class representing age and placing it within the deposit (NEVER in a scarp flank). When using this feature to assign an age, think: "This deposit has this 'Historic' age (click on the deposit polygon)."

4.4.3 Confidence

The confidence attribute provides additional context on how robust the evidence is that a landslide really exists in this location. SP-42 outlines guidance for making this determination using a point system. This

feature class allows the geologist to quickly assign a confidence value (Low, Moderate, or High) by selecting one of three symbologies for this point feature class and placing it within the deposit. When using these features, think: "The geologist has a "high" confidence (click on the deposit polygon) that this polygon landslide information is identified correctly."

4.4.4 Movement class 1 and 2

The movement class attributes are point feature classes that allow the geologist to assign a deposit's primary and secondary movement classes (for example, the type(s) of landslide). If the geologist considers there to be a secondary movement type, one must add a "Movement_Class_2" point to the same deposit polygon. **This feature is only placed within the Deposits feature class where the field DEP_SCARP = 'deposit' or DEP_SCARP = 'deposit_2'!** Refer to Appendix A, SP-42 for a complete list of movement types (Burns and Madin, 2009). Place the point choice within the deposit polygon and that attribute choice will be transferred to the deposit polygon attribute table (**Figure 4-4, Figure 4-5, Figure 4-6**). When using these features, think, for example: "This primary movement class is debris flow or 'DFL' (click on the deposit polygon)."

4.4.5 Direction

The direction attribute is a line feature class that allows the geologist to assign a landslide movement/flow direction to the deposit. Start near the high point of the deposit and end near the low point of the deposit, estimating the direction of flow via the direction the line is drawn. The suggested symbology for this line is an arrow, with the arrow pointing in the direction representing the dominant landslide movement direction. **This feature is only placed within Deposits feature class where the field DEP_SCARP = 'deposit' or DEP_SCARP = 'deposit_2'!** Draw the line completely within the deposit polygon and do not allow the line to overlap any other polygons (**Figure 4-4, Figure 4-5, Figure 4-6**). When using these features, think: "The direction of this landslide goes from this point (click on the high point of the deposit polygon) to this direction (click on the low point of the deposit polygon)."

4.4.6 Geology 1 and 2

The geology attributes are line feature classes and allow the geologist to assign to the deposit the geology map unit(s) that the landslide overlays. **This feature is only used for the Deposits feature class where the field DEP_SCARP = 'deposit' or DEP_SCARP = 'deposit_2'!** Start the line within the desired geology polygon and end the line within the desired deposit polygon (**Figure 4-4, Figure 4-5, Figure 4-6**). It doesn't matter how the line overlaps other landslide polygons, only that the beginning and end are in the correct locations. The Geology_1 feature class is the primary attribute transfer mechanism. If there is a second geology type that need to be included, use the Geology_2 feature class. A maximum of two geology types can be transferred to the deposit table. When using these features, think: "This geology (click on the geology polygon) is underlying that deposit polygon (click on the deposit polygon)!" Or in the cases of debris flow fans and rock fall/topple talus deposits "This geology (click on the geology polygon) is the source of that deposit polygon (click on the deposit polygon)."

4.4.7 Head scarp height

The head scarp attribute is a line feature class that allows the geologist to define the change in elevation from top to bottom (vertical height) of a landslide's head scarp. **This feature is used for the Deposits feature class where the field DEP-SCARP = 'scarp' or DEP_SCARP = 'scarp_2'!** These lines should be drawn completely within the scarp or scarp_2 polygon (**Figure 4-4, Figure 4-5, Figure 4-6**). Don't allow any part of the lines to overlap two or more scarp or scarp_2 polygons. The order of clicking to create line

does not matter. When using these features, think: "The scarp flank average high elevation point is here (click on the head scarp), and the average low elevation point is here (click on the head scarp)."

4.4.8 Internal scarp distances

The internal scarp attributes are line feature classes that allow the geologist to define the horizontal distance between all identified internal scarps, including the head scarp (for example, HS_IS1 = horizontal distance from bottom of head scarp to internal scarp line no. 1 (top of internal scarp). **This feature is used within the Deposits feature class where the field DEP_SCARP = 'deposit' or DEP_SCARP = 'deposit_2'!** These lines should be drawn completely within the deposit or deposit_2 polygon (**Figure 4-4, Figure 4-5, Figure 4-6**). Do not allow any part of the lines to overlap two or more deposit or deposit_2 polygons. When using these features, think: "The distance from the head scarp (click on the bottom of the head scarp) to the internal scarp line (click on the internal scarp line) OR the distance from the upper internal head scarp (click on the internal scarp line) to the lower internal scarp line (click on the internal scarp line)."

4.4.9 Fan height

The fan height attribute is a line feature class that allows the geologist to measure the change in elevation from the top of the fan to the toe. **This feature is only used for the Deposits feature class where the Movement_Class_1 attribute = DFL (fan deposits)!** Start drawing the line near the thickest part of the fan deposit polygon on the valley bottom floor and end it near the lowest point of the fan deposit polygon (**Figure 4-4**). Don't allow any part of the line to overlap with other deposit polygons. When using these features, think: "The fan's high elevation point is here (click on the fan deposit), and the low elevation point is here (click on the fan deposit)."

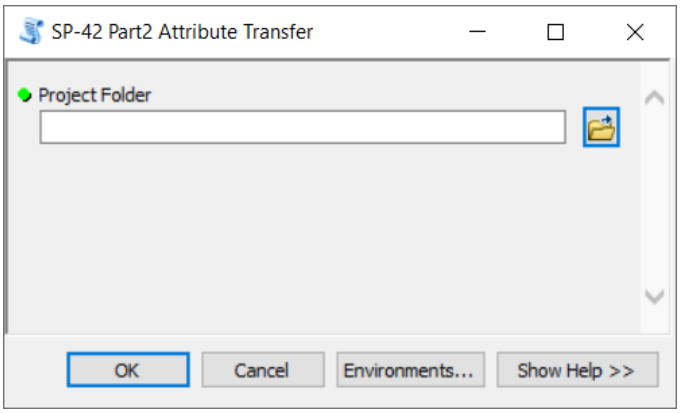
4.4.10 Slope

The slope attribute is a line feature class that allows the geologist to measure the adjacent slope angle from the deposit. Debris flow fans are an exception (Movement_Type = DFL), and for these features, the geologist is trying to estimate the slope of the ground or channel on which the deposit was deposited.
The slope feature class can be used for the scarp flank (slope angle of slope before it failed, line on inside edge) or DFL deposit type (to mimic channel slope underneath the deposit – edge of deposit) (**Figure 4-4**). For the DFL deposit type, the slope angle attribute line should be placed along the inside edge of the deposit polygon. When using these features, think: "The slope angle starts here (click in scarp flank), and the slope angle ends here (click in scarp flank)."

4.5 Step 4: Run *SP-42 Part 2 Attribute Transfer* Tool and Review

After the geologist has assigned attributes to each deposit and scarp flank in the Deposits feature class, the next step is to run the ***SP-42 Part2 Attribute Transfer*** tool. This will transfer all attribute values from the attribute feature classes to the landslide inventory attribute table (**Figure 4-7**) using spatial and attribute joins. The tool will provide a summary of each input by clicking on the [Show Help >>] button.

Figure 4-7. The SP-42 Part 2 Attribute Transfer tool user interface.



Descriptions of each input in the toolbox are as follows:

1. **Project Folder:** The 'Project Folder' input must be the SAME project folder location used in the *SP42 Part1 Base Map Setup* tool.

At the beginning of the attribution transfer process, two new feature classes are created inside the Landslide_Inventory.gdb geodatabase: Deposits_ID and Deposits_join. All attribution transfers are done within Deposits_ID, which maintains the integrity of the original data in the Deposits feature class. **All attribute checks after running the *SP-42 Part2 Attribute Transfer* tool should be done in the Deposits_ID feature class attribute table, NOT the original Deposits feature class.** The Deposits_join feature class is an intermediate dataset that propagates attribute joins during the transfer process. Once all attribute features have been placed, a review process is necessary to show the geologist where attributes are missing, were transferred incorrectly, or need to be changed.

4.5.1 Review attribute table

There are some fundamental checks that the geologist should start with when beginning the attribute QA/QC process. Start at the first step in this list and progress to the last.

1. Each polygon should have a value in the DEP_SCARP field. The tool will exit if it finds missing values in the DEP_SCARP field and display a message indicating that this is the issue. **When correcting this issue, be sure to make the changes to the DEP_SCARP field in the Deposits feature class**, otherwise the changes will not carry over when the Part 2 tool is re-run.
2. Each polygon should have a value in the UNIQUE_ID field. This field not only links scarp flanks with their related landslide deposit, but it is essential for correctly applying some of the other attributes. **Many initial attribute errors are due to the misplacement or omission of the Unique_ID line feature in the deposit or deposit/ scarp flank pair**.
3. If a landslide deposit has multiple disconnected scarp flanks, they should be merged into one polygon. Only one scarp flank polygon is assigned the UNIQUE_ID value so any others will have a <Null> value in both the UNIQUE_ID and DEP_SCARP field. This is best accomplished in an edit session.

The deposit and scarp flank attribute information will be transferred based on the DEP_SCARP field values 'deposit' or 'deposit_2' and 'scarp' or 'scarp_2', respectively. To assist the user with attribute checks, we provide **Table 4-2**, which identifies which attributes are associated with each of the two polygon types.

Table 4-2. Attribute features in the Deposits_ID feature class for landslide scarp flanks and deposits.

Attribute Type	*Scarp Flank*	*Deposit*
Age	--	Yes
Confidence	--	Yes
Direction	--	Yes
Fan_Height	--	Yes
Geology_1	--	Yes
Geology_2	--	Yes
HS_Height	Yes	--
HS_IS1	--	Yes
IS1_IS2	--	Yes
IS2_IS3	--	Yes
IS3_IS4	--	Yes
LS_Slope	Yes	Yes (Debris Flow only)
Movement_Class_1	--	Yes
Movement_Class_2	--	Yes
Unique_ID	Yes	Yes

4.5.2 Correcting attribute errors and rerunning tool

The ***SP-42 Part2 Attribute Transfer*** tool is designed so that it can be run multiple times, allowing the geologist to iteratively implement any changes to the attributes that inevitably crop up during the review process. This can be accomplished by adding, moving, or modifying the attribute features from the Attribute geodatabase and running the tool again.

Helpful Hints:

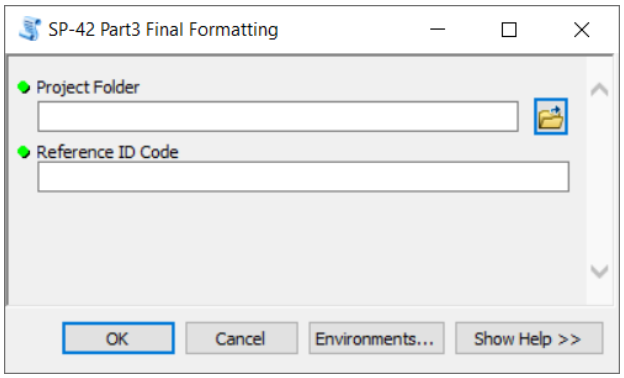
- After placing the attributes and running ***SP-42 Part2 Attribute Transfer*** tool, begin the QC process by checking for missing entries in the UNIQUE_ID field of the Deposits_ID feature class. Each landslide must contain a unique ID.

If errors in the Deposits_ID feature class attribute table remain, continue modifying the attribute features and re-running the tool until there are no more errors. However, **every time you run this tool, it will overwrite the previous outputs in the Deposits_ID attribute table.** Therefore, if you do any manual editing inside the Deposits_ID feature class and you run the Part 2 tool again, you will lose all your manual edits. For this reason, any manual editing in the Deposits_ID attribute table should come at the very end of the attribution process. For example, adding the name of a specific landslide to the 'NAME' field in the Deposits_ID feature class should be done once there is certainty that the attribute transfer tool will not need to be run again.

4.6 Step 5: Run the SP-42 Part3 Final Formatting Tool

Once creating and reviewing the landslide inventory and attribution is complete, run the ***SP-42 Part3 Final Formatting*** tool. This tool will create a new geodatabase and populate it with the final landslide inventory datasets. These final datasets are formatted for DOGAMI publication and for input into the SLIDO geodatabase. It is designed to be used after successfully running the ***SP42 Part1 Base Map Setup*** and the ***SP42 Part2 Attribute Transfer*** tools. The tool will provide a summary of each input by clicking on the [Show Help >>] button (**Figure 4-8**).

Figure 4-8. The SP-42 Part 3 Final Formatting tool user interface.



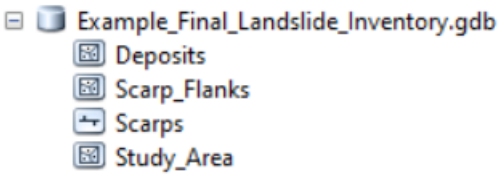
Descriptions of each input in the toolbox are as follows:

1. **Project Folder:** The 'Project Folder' input must be the SAME project folder location used in the ***SP-42 Part1 Base Map Setup*** and ***SP-42 Part2 Attribute Transfer*** tools.
2. **Reference ID Code:** This input text will go into the landslide deposit 'REF_ID_COD' attribute field.

The ***SP-42 Part3 Final Formatting*** tool first does final field calculations for a few of the attributes and cleans the Deposits_ID attribute table. It then divides the Deposits_ID feature class into Deposits and Scarp_Flanks feature classes using the DEP_SCARP value. If this tool fails, it is typically because of remaining missing attributes, particularly ones that are necessary for doing the final field calculations.

The final output is a new geodatabase called the Final_Landslide_Inventory.gdb (see the example in **Figure 4-9**). This final geodatabase contains deposits, scarp flanks, scarps, and the study area, formatted for a DOGAMI publication and incorporation into SLIDO. The datasets are then ready after there has been a final review by the geologist.

Figure 4-9. The SP-42 Part 3 Final Formatting tool user interface.



5.0 CONCLUSIONS

The purpose of this suite of tools is to increase the efficiency and precision of creating a landslide inventory dataset using the methods outlined in DOGAMI SP-42 (Burns and Madin, 2009). These tools promote a simple, straightforward, and more importantly, a visual (spatial) way of assigning attributes to the deposits and scarp flanks at the time of mapping. Fewer manual changes are likely to be needed when compared with the old style of attribution.

The following list outlines the primary advantages of using the toolbox in assisting the creation of a landslide inventory:

- The time needed for creating the base map raster and vector datasets is drastically reduced. A preparation process that typically took several days now takes hours.
- A working ArcMap .mxd file is automatically created that includes all base map, attribute, and deposit datasets. These datasets are correctly symbolized to assist the geologist in digitizing and attributing the landslide inventory.
- Because this process of assigning attributes to a landslide deposit is spatial rather than existing only in an attributes table, throughout the process the geologist can zoom to a specific landslide deposit and visually check the attributes that have been placed rather than having to review a single row of a large attributes table. Some attributes, such as direction, are automatically calculated from the attribute feature. This is a significant improvement in efficiency and accuracy when compared to the manual acquisition previously required from the geologist.
- Inventory attribute fields are automatically populated, eliminating most errors common to manual data entry. This includes misspellings, mixing upper-case and lower-case versions of the same values, blank fields, etc.
- The final landslide inventory datasets are automatically created and formatted in a separate geodatabase, maintaining the integrity of the original datasets, and protecting against irrecoverable mistakes as well as seamlessly preparing the datasets for publication and inclusion into SLIDO.

6.0 ADDITIONAL CONSIDERATIONS

In addition to the general limitations of the methods defined in SP-42, this toolset has its own set of inherent limitations. This section outlines issues that might come up when running the tools, such as:

- Maintaining the project folder structure and naming conventions starting with the ***SP-42 Part1 Base Map Setup*** tool is essential. Because the successful completion of ***SP-42 Part2 Attribute Transfer*** and ***SP-42 Part3 Final Formatting*** tools depends on the location and names of datasets within the project folder, moving or renaming geodatabases, folders, or feature classes may cause the tools to fail. This can also cause complications when accounting for multiple inventory mappers in one area or splitting study areas into multiple sections.
- With few exceptions, the tools will not flag attribute value choices made by the geologist that may be considered errors, i.e., Movement_Class = ‘earthflow’ versus Movement_Class = ‘rockfall’. It is important that the geologist has a very good understanding of the SP-42 methods, as well as a solid understanding of landslide processes (i.e., formation, structure, surficial characteristics). The tools have been designed to catch general issues that will stop the process from completing successfully, i.e., existing null values or typos.
- This process only supports automated attribution for a single deposit or a single deposit with one overlaying deposit. Attributing more than two landslides stacked on top of each other will generate value errors and all will need to be attributed manually. Remember to reserve manual attributions until you are ready to run the ***SP-42 Part3 Final Formatting*** tool.
- Mapped landslides that overlap the edge of the study area may have to be attributed manually. Remember to reserve manual attributions until you are ready to run the ***SP-42 Part3 Final Formatting*** tool.

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8.0 REFERENCES

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