LANDSLIDE MAPS OF UTAH

Ashley H. Elliott and Kimm M. Harty

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Cover photo: *Landslide in Seely Creek drainage, central Utah.*

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ABSTRACT

Significant economic losses are associated with landslides, and Utah contains numerous landslides and landslide-prone geologic units. Exposure to landslide hazards increases as development expands onto hillsides and other landslide-prone areas. To improve the understanding of landslides and their distribution throughout Utah, we used a geographic information system (GIS) to compile previously mapped landslides throughout Utah. The result consists of 46 1:100,000-scale landslide maps created from three feature classes (LandslidePolygons, LandslideScarps, and DebrisFlowPaths). The layers include over 22,000 landslide deposits in addition to landslide scarps and debris-flow travel paths throughout the state. Also included with the feature classes are GIS dataset attributes, which can be used to identify more specific information about each landslide (such as landslide map unit, type of material and movement, possible movement causes, landslide-prone geologic units, and original map references). This study can aid in land-use planning by identifying areas susceptible to landslide movement, which require site-specific geologic-hazard and geotechnical investigations prior to development.

INTRODUCTION

Landslides have caused significant economic losses in Utah. During 1983 and 1984, heavy precipitation and rapid snowmelt resulted in landslides and flooding that caused significant losses (more than $300 million) (Christenson and Ashland, 2007). More recently, heavy precipitation during 2005 and 2006 caused an excess of $10 million in statewide losses associated with landslides (Christenson and Ashland, 2007). Most landslides in Utah generally result from the reactivation of pre-existing landslides or hillside modification of landslide-prone geologic units; both pre-existing landslides and landslide-prone geologic units are identified in this study. As development continues along steep slopes and in mountainous regions of the state, understanding the distribution of landslides becomes increasingly important. For this reason, we used a geographic information system (GIS) to update the 1:100,000-scale landslide maps of Utah (Harty, 1992, 1993), which are compilations of previously mapped landslides from pre-1989 published and unpublished sources. This study adds previously mapped landslides documented from 1989 to mid-2007 on geologic maps and in inter-

nal Utah Geological Survey (UGS) landslide investigations, herein collectively referred to as "new data." These new data allowed us to refine some of the existing landslide boundaries in Harty (1992, 1993) and add approximately 12,000 landslides to the previous compilations. This study includes three Environmental Systems Research Institute (ESRI) file geodatabase feature classes (LandslidePolygons, LandslideScarps, and DebrisFlowPaths) and associated GIS dataset attributes. The landslide data included in the feature classes are displayed on 46 1:100,000-scale topographic maps (figure 1). We intend that the feature classes, GIS dataset attributes, and landslide maps will be updated periodically as new information becomes available.

The landslide maps display more than 22,000 landslides deposits that cover more than 5% of Utah. The landslide deposits shown are primarily classified by the estimated depth to the surface of rupture (deep or shallow), by probable earthquake origin where applicable (lateral spread and/or flow failure), or grouped with other Quaternary deposits (undifferentiated). In addition to landslide deposits, the maps also show landslide scarps and debris-flow travel paths. Information associated with the landslides is stored in the GIS dataset attributes of each feature class (see table 1 for a list of attributes).

The landslide feature classes, associated GIS dataset attributes, and landslide maps (created using the landslide feature classes) are provided in GIS format that can be viewed using ESRI's ArcMap or free ArcExplorer software. The landslide maps are also provided on this DVD in PDF format.

Understanding landsliding in Utah is necessary for reducing future landslide-related losses. The maps and associated feature classes provide a way to identify the location and extent of previous landsliding and, in conjunction with the GIS dataset attributes, will aid in land-use planning by identifying landslide map units, type of material and movement, landslide-prone geologic units, and possible causes of landslide movement. Although proper planning and avoidance of landslide-prone areas are the best ways to reduce landslide-related losses, avoidance is not always possible. Where avoidance is not possible, site-specific geotechnical investigations can identify engineering techniques that may be used to stabilize slopes or reduce the impacts from landslides.

Figure 1. *Index of 30' x 60' quadrangle maps for Utah. Quadrangle names and landslide map plate numbers shown.*

Table 1. *Description of GIS dataset attributes.*

GIS Dataset Attribute	ESRI File Geodatabase Feature Class			Description
	Landslide Polygon	Debris Flow Paths	Landslide Scarps	
StateLSID	X			Arbitrary number assigned to identify individual landslides. In areas where individual landslides are represented by multiple polygons, the same StateLSID number is used to identify individual landslide deposits.
LSUnit	X	X	X	Landslide map unit. See text and table 5 for description of landslide types.
MoveType	X	X		Landslide classification as defined by Cruden and Varnes (1996) (table 4).
Historical	X	X	X	Identifies known historical (1847–present) landslides. "Yes" for historical landslides; otherwise left blank if the age is prehistoric or undetermined.
GeolUnit*	X			Landslide map unit in the original source.
MapScale*	X	X	X	Original map reference scale, exact or approximate value. "Unknown" indicates original source is no longer available to check the scale. "Various" indicates publication having figures of varying scales which were used to compile our landslide maps.
MapName*	X	X	X	Shortened version of original map reference name; usually area studied.
PubDate*	X	X	X	Original map reference publication date.
Author_s*	X	X	X	Original map reference author(s). If more than two authors, "and others" was used to save space.
MapBound	X	X	X	Identifies landslide polygons that cross the original source map boundary. "Yes" for landslide polygons having a boundary that corresponds to a study area boundary and not necessarily a landslide boundary; otherwise left blank.
MultSource	X			Identifies polygons merged from multiple sources. "Yes" for landslide polygons merged from multiple sources; otherwise left blank. Information from the most accurate or largest polygon used to identify the original source (columns "GeolUnit," "MapScale," "MapName," "PubDate," and "Author_s").
AffUnit	X			Geologic unit(s) likely incorporated into the landslide mass. All units listed are geologic formations unless otherwise indicated. "?" indicates units queried by this study. "(?)" indicates units queried by the original source's author(s).
MoveUnit	X			Geologic unit(s) likely involved in the surface of rupture. All units listed are geologic formations unless otherwise indicated. In addition to signifying multiple possible units involved in landsliding, "and/or" is used to indicate the surface of rupture may be at the contact between the two units. "?" indicates units identified with uncertainty by this study. "(?)" indicates units identified with uncertainty by the original source's author(s).
MoveCause	X			Identifies the possible cause of landsliding when identified in the original source. Abbreviations used in this and the "Notes" column are listed in table 2.
Notes	X	X	X	Stores additional information about the landslide that was available in the original source. Abbreviations used in this and the "FailCause" column are listed in table 2.

* These attributes may include information from multiple sources that mapped a landslide feature identically (i.e., the landslide feature is not a result of merging multiple features). All sources for the landslide feature are listed, separated by a semicolon (;). The order of the sources for each field is the same (for example, if the "Map Name" is "Circle Cliffs 1 SW; Circle Cliffs area" and the "PubDate" is "1958; 1967", the Circle Cliffs 1 SW map would correspond to the 1958 publication date and the Circle Cliffs area map would correspond to the 1967 publication date).
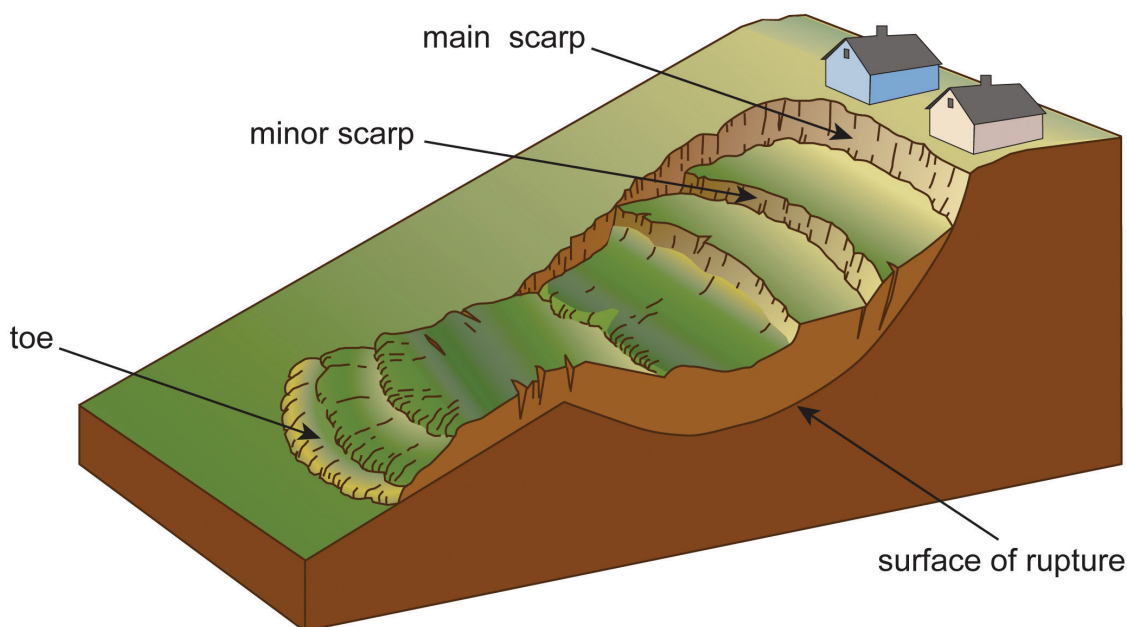
Figure 2. Generalized depiction of a landslide showing the main scarp, minor scarp, toe, and surface of rupture. Modified from Varnes (1978).

PREVIOUS WORK

Many site-specific landslide studies have been completed for various regions of the state, mostly within U.S. Forest Service districts. However, only a few statewide landslide studies exist. Shroder (1971) compiled one of the first statewide studies by identifying approximately 600 landslides scattered throughout the state. Of these 600 landslides, Shroder (1971) conducted fieldwork to characterize 32 landslides and landslide zones.

Harty (1991) compiled the first statewide landslide map from all known published and unpublished sources up to 1989. Published sources primarily consisted of geologic maps, and landslide-specific studies. Unpublished sources consisted of landslide maps prepared by federal, state, and local governments; geologic maps from university theses and dissertations; and geotechnical consultants' reports. The resulting 1:500,000-scale map included more than 10,000 landslides. In addition to the statewide landslide map, Harty (1992, 1993) also compiled 46 1:100,000-scale landslide maps. These maps were compiled from the same information used to create the statewide 1:500,000-scale map (Harty, 1991). In conjunction with the maps compiled by Harty (1991, 1992, 1993), an unpublished landslide database was created. The database included information on approximately 2200 of the landslides and identified landslide locations, dimensions, slope angles, orientations, age, geologic units involved, and possible cause of movement. We have incorporated most of the original database into the GIS dataset attributes of this study.

LANDSLIDE CLASSIFICATION

Landslide deposits included in the "LandslidePolygons" feature class are displayed and classified, where possible, based on the estimated depth to the surface of rupture (figure 2). Within the GIS dataset attributes, landslides may be further classified based on age and type of movement. Landslides mapped with approximate boundaries or uncertainty in the original source are not classified separately, but rather included with other landslide deposits (as defined below).

The depth to the surface of rupture of landslide deposits is classified as deep (10 feet [3 m] or more) or shallow (less than 10 feet [3 m]). Shallow landslides are grouped separately from deep landslides because they have different hazard characteristics. Shallow landslides are more likely to move rapidly, run out over long distances, and be life-threatening. These include debris flows and debris slides, as well as other small shallow landslides. In Utah, deep landslides generally move slower and cover shorter distances. These include earth flows, complex landslides, rotational and translational landslides, as well as some large debris slides that, because of their size and morphology, likely have a deep surface of rupture. Besides movement rates and run-out distances, deep and shallow landslides also differ morphologically. Figures 3 and 4 show examples of deep and shallow landslides. Included in the "deep or unclassified landslide" unit are landslides for which a type designation (such as debris slide, debris flow, earth flow) was not reported in the original source and landslides where the depth to the surface of rupture is unknown.
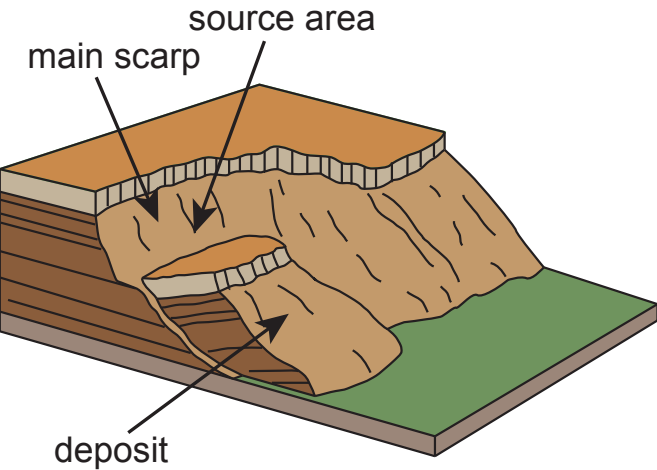
Figure 3. *An example of a deep landslide with a surface of rupture ≥10 feet (3 m) deep. Modified from Varnes (1978).*
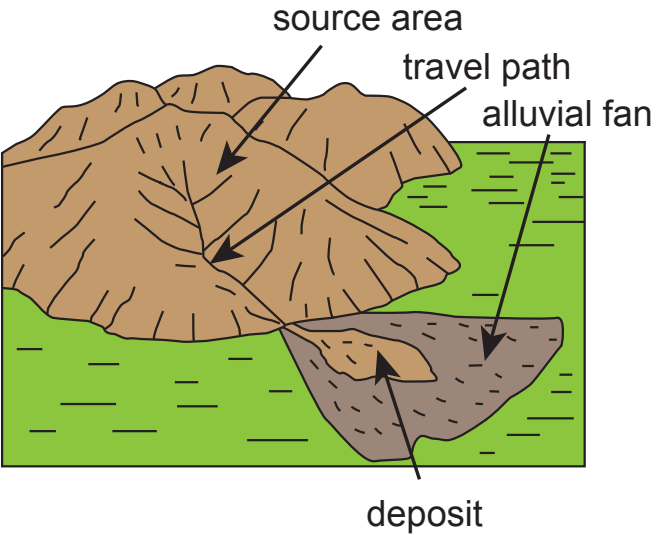

Figure 4. *An example of a shallow landslide(debris flow) with a surface of rupture <10 feet (3 m) deep.*

Table 2. *Abbreviations used in the GIS dataset attributes "FailCause" and "Notes" columns.*

Abbreviation	Definition
ave	average
btwn	between
B.P.	before present
combo.	combination
deg.	degree/degrees
dep.	deposit
deps.	deposits
df	debris flow
E	East
Fm.	formation
ft	feet
geol.	geologic
lcstrn	lacustrine
ls	landslide
m	meters
mat.	material
N	North
org.	original
precip.	precipitation
Quat.	Quaternary
rd	road
ref.	reference
S	South
sat	saturation
sed.	sediment
Tert.	Tertiary
tuff.	tuffaceous
W	West
yrs	years

Where possible, we have identified landslides that have known historical (1847–present) movement in the GIS dataset attributes ("Historical" column in the GIS dataset attributes). We also identified all shallow landslides as historical, because many of these landslides moved during 1983 and/or 1984, and those of unknown age are assumed to be historical because shallow landslides are usually difficult to identify within one to 15 years after their occurrence (U.S. Geological Survey, 1982). All other landslides are classified as historical only if historical movement has been documented by others.

In addition to classifying landslides based on depth to surface of rupture and historical movement, we also classified landslides based on the type of movement. This classification generally follows that of Cruden and Varnes (1996). According to their definition, the term "landslide" is used to describe any downslope movement of rock, debris, or earth including falls, flows, and slides, and thus is not solely limited to "sliding" of "land." The various types of movement are defined in table 3. The Cruden and Varnes (1996) landslide classification uses two words; the first word describes the type of material (rock, debris, or earth) and the second word describes the type of movement (slide, flow, fall, spread, or topple). Table 4 gives examples of possible landslide types using Cruden and Varnes' (1996) two-word classification. In addition to the landslide types listed in table 4, composite and complex landslides, defined by Cruden and Varnes (1996) as specific modes of sliding, are also included. Composite landslides are those in which different movement types may occur in different areas of the landslide mass, sometimes simultaneously. Complex landslides involve a combination of two or more types of movement that occur in sequence.

The landslide-deposit map units represent landslides dis-

Table 3. *Landslide movement types and corresponding definitions, simplified from Cruden and Varnes (1996).*

Type of Movement	Definition
Slide	Downslope movement of soil or rock that occurs on a rupture surface or on thin zones of intense shear strain. A continuum exists between slides and flows.
Flow	Spatially continuous movement in which the shear surfaces are closely spaced and short-lived. Often resembles a viscous liquid.
Fall	Detachment of soil or rock from a steep slope. The detached material then moves downslope by falling, bouncing, or rolling.
Spread	Extension of a cohesive mass (either rock or soil) combined with the general subsidence of that mass into softer underlying material.
Topple	Forward rotation of a mass of soil or rock about a point or axis. Topples are created by freeze-thaw actions, or are driven by gravity.

Table 4. *Landslide classification of Cruden and Varnes (1996) based on type of material and movement.*

Type of Movement	Type of Material		
	Bedrock	**Predominantly Coarse**	**Predominantly Fine**
Fall	Rock fall	Debris fall	Earth fall
Topple	Rock topple	Debris topple	Earth topple
Slide	**Rock slide**	**Debris slide**	**Earth slide**
Spread	Rock spread	Debris spread	Earth spread
Flow	Rock flow	**Debris flow**	**Earth flow**

Bold indicates landslide types identified by the original source and included in the attributes. All other types, except rock falls and topples, were not identified in the original sources. Rock falls and topples are common in Utah and their deposits are often mapped as talus. Compiling their occurrence was beyond the scope of this study.

tinguished by the estimated depth to the surface of rupture (deep or shallow), landslides having a probable earthquake origin (lateral spread and/or flow failure), or landslides grouped with other Quaternary deposits (undifferentiated). We used descriptions of the landslide deposit(s) in the original source (such as map unit descriptions that give estimated depth of the deposit) to classify landslides accordingly. In addition to landslide deposits, the landslide maps also include landslide scarps ("LandslideScarps" feature class) and debris-flow travel paths ("DebrisFlowPaths" feature class). Table 5 lists the landslide map units and features.

GIS DATASET ATTRIBUTES

The GIS dataset attributes can be used to identify specific information about a landslide, including estimated depth to the surface of rupture, type of movement, episodes of historical landsliding, possible geologic units involved in landsliding, possible cause of movement, and original source information (which provides a reference to more specific information). Table 1 lists the 15 different attributes compiled for this study. The GIS dataset attributes

include information from the unpublished landslide database created in conjunction with the maps of Harty (1991, 1992, 1993). However, information about the dimensions, orientation, and slope angle has been excluded in the GIS dataset attributes of this study because such information can be easily calculated using GIS. Due to the variability of the original map references, not all landslides, landslide scarps, or debris-flow travel paths have information for each attribute.

COMPILATION METHODS

This study began with the digitization of the earlier UGS 30' x 60' landslide maps (Harty, 1992, 1993) by the Utah Automated Geographic Reference Center (Utah AGRC) (2006b). We then digitized landslides documented in the 1989 to mid-2007 new data. These updates were initially stored in separate feature classes, for ease in comparing and digitizing updated information. Once all updates were digitized, we merged the new data with the existing landslide data (Harty, 1992, 1993) to create three feature classes ("LandslidePolygons," "LandslideScarps," and "DebrisFlowPaths") and the associated GIS dataset attributes.

Table 5. *Description of landslide map units and features. Where possible, landslide map units are based on the estimated depth to the surface of rupture and are reported in the GIS dataset attributes (in bold).*

Unit Description

Deep or unclassified landslide – Generally 10 feet (3 m) thick or more and shows characteristic landslide morphology. May include areas of complex or composite landsliding where landslide density is too great to show individual landslides separately. Also includes unclassified landslides where original source did not define the depth to surface of rupture.

Shallow landslide – Generally less than 10 feet (3 m) thick and shows characteristic landslide morphology. This map unit consists mainly of debris slides and debris flows. May include some composite landslides.

Lateral spread and/or flow failure – Liquefaction-induced landslides typically associated with earthquakes; generally occur on very gentle slopes or flat terrain.

Landslide undifferentiated from talus and/or colluvial deposits – May include deep or shallow landslides mapped with talus and/or colluvial deposits.

Landslide and/or landslide undifferentiated from talus, colluvial, rock-fall, glacial, and soil-creep deposits – May include deep or shallow landslides mapped with talus, colluvial, rock-fall, glacial, and/or soil-creep deposits; principally mapped and compiled by Roger B. Colton, U.S. Geological Survey (see reference lists for Colton's landslide maps).

Landslide scarp – Landslide feature generally found near the head (top – see figure 2). Identified as the area where landslide material has moved downslope and away from the undisturbed ground. Locally includes scarps associated with sackungen, although identification as such is rare in Utah.

Debris-flow travel path – Identifies the travel path of a debris flow (shallow landslide).

Due to the complexities of this process, including data discrepancies, we developed rules so that all data in the two datasets were merged in a consistent manner. The appendix contains a detailed set of rules applied when merging the data. Once the merging process was complete, we used the feature classes to create 46 1:100,000-scale maps that cover the state. We intend that the feature classes, GIS dataset attributes, and maps will be updated periodically to incorporate new landslide information as it becomes available.

Although the original landslide compilation (Harty, 1992, 1993) included landslides documented in many unpublished sources, including geotechnical consultants' reports, sources of data included in this update are mostly published geologic maps by the UGS and U.S. Geological Survey (USGS), and unpublished information from internal UGS landslide investigations. Searching through the vast files of numerous consultants was beyond the scope of this study. However, the update includes more than 240 new and sometimes more accurate sources of information regarding landslide shape, size, and location. The sources of data for each map can be found in the "Source Documents" folder within the "Documents" folder on this DVD.

USE OF THE DATA AND LANDSLIDE HAZARD REDUCTION

The three feature classes (LandslidePolygons, LandslideScarps, DebrisFlowPaths) and the associated GIS dataset attributes identify landslides, landslide scarps, and debris-flow travel paths. Local jurisdictions, developers, geotech-

nical consultants, the general public, and others can use this information to identify areas that have been subject to landslides, the estimated depth to the surface of rupture, and in many cases the type of material and movement. This study can also be used to aid in regional land-use planning by identifying landslide-prone geologic units ("MoveUnit" column in the GIS dataset attributes), possible causes of landslide movement ("MoveCause" column in the GIS dataset attributes), and areas that have been subjected to known historical landsliding ("Historical" column in the GIS dataset attributes).

The most effective way to reduce the risk from landslide hazards is through proper planning and avoidance, which is possible if landslides and landslide-prone areas are identified early in the planning and design process (Black and others, 1999). This study identifies mapped landslides, which pose a significant hazard to all development because the level of stability is usually marginal under natural conditions (Machan, 2006). The UGS does not recommend development on pre-existing landslides without mitigation measures that avoid a reduction in stability and preferably, increase the level of stability. Such mitigation measures should be supported by geologic-hazard and geotechnical investigations. If development is proposed in a pre-existing landslide or landslide-prone area, a site-specific geologic-hazard and geotechnical investigation should be performed early in project design to establish whether conditions for landsliding are present at a site. If such conditions exist and avoidance is not possible, the geotechnical consultant should provide appropriate engineering recommendations to design cuts and fills, establish site drainage, and where necessary, recommend landslide-control and slope-stabilization measures. Such

measures, including careful and appropriate site grading, proper placement, compaction, and control of materials within fills, and engineering of cut slopes, are necessary for successful hillside development. Careful attention to site drainage and dewatering of shallow ground water or ponded surface water may improve slope stability. Retaining structures and buttresses at the toe of slopes and tiebacks that penetrate the landslide mass, pinning it to underlying stable material, may help stabilize some landslides. Other techniques used to reduce landslide hazards include bridging or weighting slopes with compacted earth fills. Installation of landslide warning systems can reduce the risk posed by landslides (Keller and Blodgett, 2006). Landslide investigations and design of mitigation measures should be performed by licensed geologists and engineers, working together as a team, who have the necessary education, training, and experience in dealing with landslides.

In addition to slope stabilization, other measures may be effective in reducing the risk posed by landslides. Building setbacks and site plan layout modification, such as the location and orientation of buildings, can help reduce the area exposed to potential landslide movement. Installation of landslide warning systems (Keller and Blodgett, 2006) and instrumentation, such as piezometers and inclinometers, to monitor site conditions and effects can aid in identifying signs of landslide movement, but require ongoing maintenance by experienced personnel. Engineered retention basins, deflection berms, or other specialized engineering designs can be used to address nearby, but offsite, hazards such as debris slides and debris flows. Special engineering designs can be used to minimize the damage caused by minor movement. Turner and Schuster (2006) provides more information about landslide and slope-stabilization mitigation measures.

LIMITATIONS

This study incorporates previously mapped landslides from selected published sources and unpublished UGS landslide investigations through mid-2007. Field checks were not performed, and the reliability of the landslide information is dependent on the accuracy and quality of the original source maps, which vary. In addition, some landslides may have been missed or otherwise not documented by the original source and therefore do not appear in this study. Landslides may exist in areas not covered by detailed geologic maps. Because this study excludes landslides documented in many unpublished sources, other landslides may exist that are not shown on these maps. Some landslide boundaries shown on the maps correspond to study-area boundaries and are not necessarily landslide boundaries (identified in the "MapBound" column of the feature classes). We made no attempt to extend landslide boundaries beyond that delineated on the original source maps.

The landslide maps are not intended for use at scales larger than 1:100,000, and are designed for general planning purposes to indicate the need for site-specific landslide investigations. Due to planned periodic updates, users should check for updated versions. Contact the UGS Geologic Hazards Program for more information.

SUMMARY

Landslides have caused significant economic losses in Utah. In an effort to help identify areas of the state affected by landslides, we compiled landslide data and maps covering the state of Utah using existing landslide data (Harty, 1991, 1992, 1993) and new landslide data (primarily 1989 to mid-2007 geologic maps and internal UGS landslide investigations). The data and maps were compiled using GIS and include feature classes (LandslidePolygons, LandslideScarps, and DebrisFlowPaths) with associated GIS dataset attributes. This information can be used to identify potential landslide hazards and the need for site-specific geologic-hazard and geotechnical investigations in areas of proposed development.

ACKNOWLEDGMENTS

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APPENDIX

PROCESS OF MERGING EXISTING AND NEW LANDSLIDE DATA

PROCESS OF MERGING EXISTING AND NEW LANDSLIDE DATA

When merging the new data with the existing landslide compilation of Harty (1992, 1993), several issues arose. These issues include:

- deciding which mapped boundary to use when a landslide boundary differed among different source maps,
- emphasizing units that are more likely to be actual landslides rather than other types of surficial deposits,
- deciding which attribute information to keep when merging landslide deposit polygons, and
- deciding which line(s) to keep in areas where debris-flow travel paths and/or landslide scarps crossed each other.

The following describes the rules we applied to resolve these issues. All rules are stated in hierarchical order. Rules applied to polygons ("LandslidePolygons" feature class) are separated from those applied to lines ("LandslideScarps" and "DebrisFlowPaths" feature classes). Figure A-1 summarizes the process we used for merging polygons; more detail of this process is given below.

Polygon Rules

Rules applied to the "LandslidePolygons" feature class for different data discrepancy scenarios:

Overlapping Polygons of Different Landslide Map Units

Table 5 in the text includes a description of the different landslide map units.

1. Choose "shallow landslide(s)" over "deep or unclassified landslide(s)." This rule was applied because shallow landslides are generally smaller. An exception to this rule applies when a deep landslide is much smaller or the boundary is more accurate (we determined which boundary was more accurate by examining 2006 National Agriculture Imagery Program [NAIP] imagery available from the Utah AGRC [2006a]). In these cases the deep landslide was clipped-out of the surrounding shallow landslide.
2. Choose "deep or unclassified landslide(s)" and "shallow landslide(s)" over "lateral spread(s) and/or flow failure(s)." This rule was applied because deep landslides and shallow landslides are generally smaller.
3. Choose "deep or unclassified landslide(s)," "shallow landslide(s)," and "lateral spread(s) and/or flow failure(s)" over "landslide(s) undifferentiated from talus and/or colluvial deposits" and "landslide(s) and/or landslide(s) undifferentiated from talus, colluvial, rock-fall, glacial, and soil-creep deposits." This rule was applied because deep landslides, shallow landslides, and lateral spreads and flow failures are identified specifically as landslide deposits, whereas the other landslide map units are landslide deposits undifferentiated from other Quaternary deposits.
4. Choose "landslide(s) undifferentiated from talus and/or colluvial deposits" over "landslide(s) and/or landslide(s) undifferentiated from talus, colluvial, rock-fall, glacial, and soil-creep deposits." This rule was applied because landslides undifferentiated from just talus and/or colluvial deposits are undifferentiated from fewer Quaternary units, and the likelihood of an actual landslide occurring within this map unit is higher than in the "landslide(s) and/or landslide(s) undifferentiated from talus, colluvial, rock-fall, glacial, and soil-creep deposits" map unit.

Overlapping Polygons of the Same Landslide Map Unit

Figure A-1 shows the basic process we used to merge overlapping polygons of the same landslide map unit. However, figure A-1 lacks detailed information on how we determined smaller discrete landslides, which landslide boundary was most accurate for similar landslide boundaries, or which attributes we used when merging landslide polygons. We describe this information below.

Smaller discrete landslides:

1. Use the 2006 NAIP imagery (AGRC, 2006a) to determine where smaller discrete landslides exist.
2. Where smaller discrete landslides are difficult to identify using the 2006 NAIP imagery (AGRC, 2006a), clip-out smaller landslide polygons (≤ 25% of the overlapping, larger polygon area) as discrete landslides. This rule was used to preserve some detail that would aid in regional planning.
3. Where smaller discrete landslides are difficult to identify using the 2006 NAIP imagery (AGRC, 2006a), and the ≤ 25% rule does not apply, assign landslide polygons with the largest map scale (of the original source) as discrete.

```
                                    ┌──────────────┐
                                    │  Merge Data  │
                                    └──────────────┘
        ┌──────────────────┐   ┌──────────────────┐   ┌──────────────────┐
        │ Non-overlapping  │   │ Overlapping land-│   │ Overlapping land-│
        │   landslides     │   │ slides of same   │   │ slides of differ-│
        │                  │   │ landslide map    │   │ ent landslide    │
        │                  │   │ unit             │   │ map units        │
        └──────────────────┘   └──────────────────┘   └──────────────────┘
```
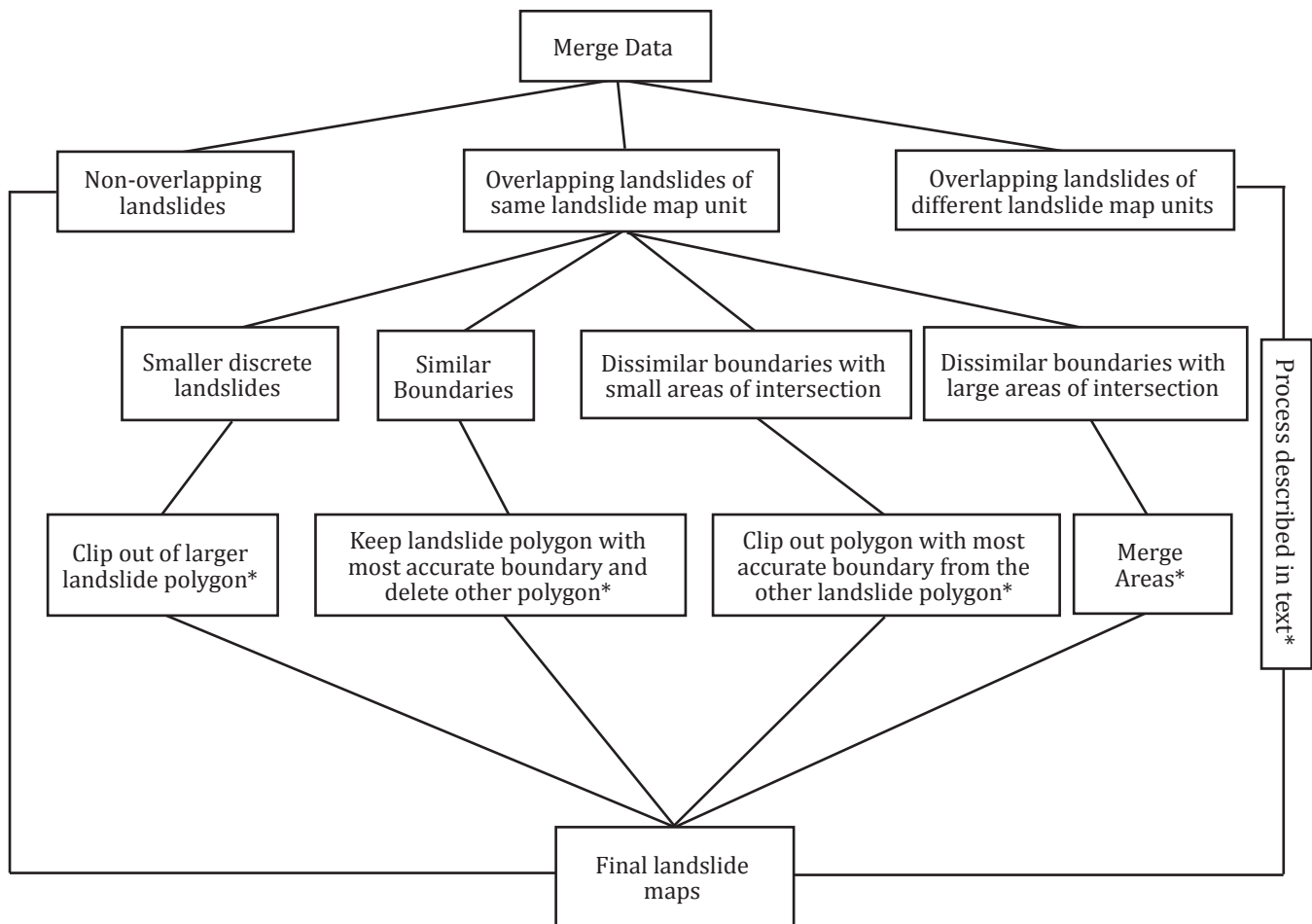

Figure A1. *Flow chart showing the process of merging landslide polygons of the previous landslide maps with the new data. *See appendix text for further explanation.*

An exception to these rules applies in areas of densely spaced landslide polygons. In these areas, small, discrete landslides are not clipped-out for simplification.

Similar boundaries:
1. Where the landslide is mapped by the same author, but in different publications, use the most recent data.
2. Where the same landslide is mapped by different authors, identify the most accurate boundary using the 2006 NAIP imagery (AGRC, 2006a).
3. Where the landslide is mapped by different authors and the most accurate boundary cannot be determined using the 2006 NAIP imagery (AGRC, 2006a), choose the boundary used in the source having the largest map scale.

Dissimilar boundaries with small areas of intersection:
1. Clip-out the most accurate boundary as identified on the 2006 NAIP imagery (AGRC, 2006a) from the overlapping landslide polygon.
2. Clip-out the smaller polygon from the overlapping landslide polygon.
3. Clip-out the landslide polygon whose boundary was used in the source having the largest map scale from the overlapping landslide polygon.

Dissimilar boundaries with large areas of intersection:
For landslides having dissimilar boundaries and large areas of overlap, where we merged the polygons together, we applied the following hierarchical listing of rules to determine which original source information would be preserved in the GIS dataset attributes:
1. Keep the attributes of the largest polygon.

2. If no polygon is the "largest," then keep the attributes of the polygon whose boundary was used in the original source having the largest map scale.
3. In cases where merging a Harty (1992, 1993) landslide polygon with new data, where no polygon is significantly larger and map scales are the same, keep the new data attributes.

We made note of where polygons were merged in the "MultSource" field of the GIS dataset attributes (see table 1).

Line Rules

When merging the line files ("LandslideScarps" and "DebrisFlowPaths" feature classes) we applied different methods and rules. For debris-flow travel paths, we kept all data even if one path crossed another path or landslide scarp because this is not an uncommon occurrence in nature. For landslide scarps that crossed each other, we applied the following hierarchical rules:

1. Choose the most accurate scarp based on the NAIP 2006 imagery (AGRC, 2006a).
2. Choose the scarp having the most associated publications.
3. Choose the scarp that was mapped at the largest map scale.
4. Choose the upslope scarp.

Where landslide scarps overlapped, the area of overlap on the shortest scarp was deleted.