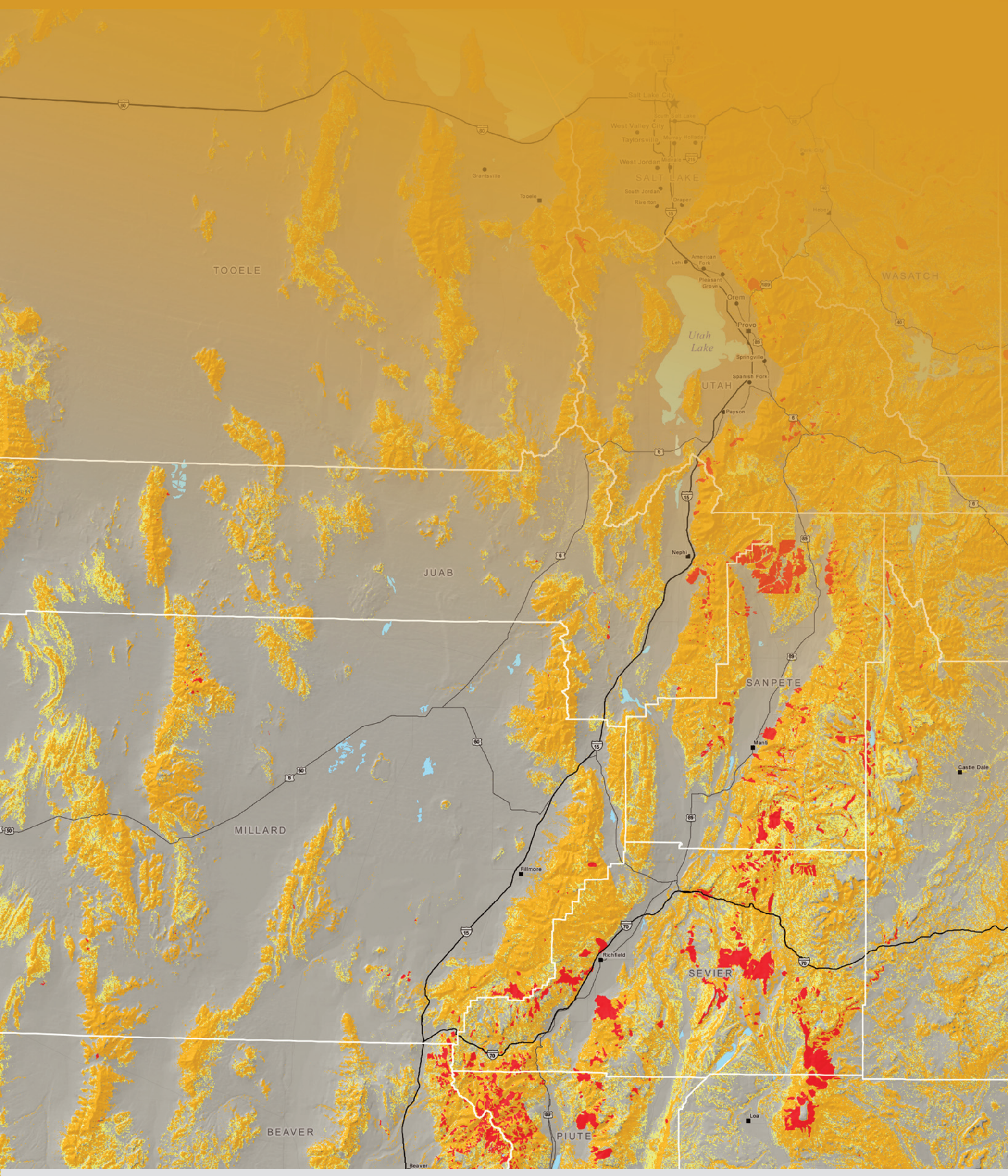
LANDSLIDE SUSCEPTIBILITY MAP OF UTAH

by Richard E. Giraud and Lucas M. Shaw



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UTAH GEOLOGICAL SURVEY
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2007

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Cover Inset Photos
Top: Landslide in the Cottonwood Creek tributary to Ephraim Canyon four miles southeast of Ephraim.
Middle: Landslide in the Browns Hole tributary to Dead Horse Canyon 13 miles southeast of Salina.
Bottom: Landslide in the South Fork of North Creek five miles northeast of Mount Pleasant.

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THE UTAH GEOLOGICAL SURVEY
contact
1594 W. North Temple, Suite 3110
Salt Lake City, UT 84116
telephone: 801-537-3300
fax: 801-537-3400
Web site: http://geology.utah.gov

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LANDSLIDE SUSCEPTIBILITY MAP OF UTAH

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ABSTRACT

We used a landslide database and geology and slope maps to produce a statewide 1:500,000-scale landslide susceptibility map of Utah using a Geographic Information System. Susceptibility categories were established using mapped landslides, geologic units, and statistic-derived landslide slope-angle thresholds in each unit. Where statistics could not be used because of small sample size, slope-angle thresholds were assigned using thresholds established for other geologic units of similar age and composition. Statistical methods provide a consistent technique to assign slope-angle thresholds and limit the use of judgment in assigning thresholds. The high susceptibility category includes all mapped landslides because they have the greatest potential to reactivate. Moderate, low, and very low susceptibility categories are assigned using landslide slope-angle thresholds.

Landslides have caused significant economic loss in Utah and as development continues to expand into landslide prone areas, the exposure to landslide hazards increases. The landslide susceptibility map shows areas of the state vulnerable to landsliding. The map is at a statewide scale and designed for general planning to determine areas where landslide hazards may exist and more detailed landslide hazard studies are needed for planning and development.

INTRODUCTION

We prepared a 1:500,000-scale landslide susceptibility map (plate 1) to show generalized landslide hazard in Utah. Landslides are downslope movements of rock or soil under the influence of gravity that may pose a risk to life and property. We used a landslide database and geology and slope maps to designate landslide susceptibility categories based on mapped landslides, geologic units, and landslide slope-angle thresholds established for geologic units.

We used a Geographic Information System (GIS) to store, organize, sort, and analyze data and to display our landslide susceptibility categories on the map. GIS is a powerful tool for the analysis of factors that cause landslides. We used a GIS to analyze landslide slope angles within geologic units to determine landslide susceptibility categories. Using a GIS allowed us to use an iterative process to test and improve our method of determining landslide susceptibility.

The purpose of the susceptibility map is to convey the relative likelihood of landsliding using susceptibility categories. The map shows landslides and slope areas that can potentially generate landslides. The map categories show the susceptibility for sliding types of movement (Cruden and Varnes, 1996). The map does not show the susceptibility for all types of movement and excludes falls, topples, spreads, shallow flows, or earthquake-induced landslides.

Landsliding is a geologic hazard that causes significant annual economic loss in Utah. Years with above-normal precipitation generally produce the most landslides (Harty, 1991; Ashland, 2003). The landslides in the wet year of 1983 had a total estimated direct cost exceeding $250 million (Anderson and others, 1984). The 1983 Thistle landslide in Utah County is recognized in terms of direct and indirect costs as the most expensive individual landslide in North America (Schuster, 1996). Utah contains numerous landslides and landslide prone geologic units. As development spreads into landslide terrain, the potential for landslide damage to private property and public infrastructure increases.

METHODS

The method used to produce the susceptibility map was constrained by the available statewide data, which include a landslide database, and geology and slope maps. The landslide database (Utah Automated Geographic Reference Center [Utah AGRC], 2006a) shows mapped landslides compiled at 1:100,000 scale (Harty, 1992, 1993). The

1:500,000-scale geologic map (Hintze and others, 2000) shows geologic units and general lithologies. A 30-meter slope map derived from the National Elevation Dataset (NED) (Utah AGRC, 2006b) allows measurement of landslide slope angle and area. Our approach uses mapped landslides and landslide slope angles to show relative landslide susceptibility categories. Producing a statewide landslide susceptibility map is difficult due to the diverse geology, terrain, and scale of information available.

We use mapped landslides and landslide slope angles in each geologic unit to establish landslide susceptibility categories. Mapped landslides are assigned a high susceptibility. Outside of mapped landslide areas, the slope angles on which landslides are known to occur were used to determine landslide susceptibility categories. Moderate, low, and very low susceptibility categories are assigned using landslide slope-angle thresholds. We calculate the average landslide slope angles within each geologic unit and plot a frequency distribution of landslide slope angles to show average angle and the range of slope angles. Slope-angle thresholds are set using standard-deviation breaks of the frequency distributions. Statistical methods provide a consistent reproducible technique to assign slope-angle thresholds and reduce the use of judgment in assigning thresholds. Where a small number of landslides in a geologic unit prevented the use of statistical techniques, slope-angle thresholds were assigned using standard deviation breaks from another geologic unit with similar age and lithology. The susceptibility categories were applied to the map using mapped landslides, and geologic units and the slope map. The GIS datasets and processes, statistical analysis, and other steps used to prepare the map are shown in figure 1. Landslide databases and geologic maps are commonly used to produce landslide susceptibility maps (Soeters and van Westen, 1996) and average landslide slope angles and geologic units have been used elsewhere in Utah to evaluate landslide susceptibility at a scale of 1:24,000 (Hylland and Lowe, 1997).

Our ability to map landslide susceptibility is limited by the resolution of the source data. The scale of the susceptibility map is controlled by the smallest scale of the source data, which is the 1:500,000-scale geologic map. Portraying landslide susceptibility at the landslide database scale of 1:100,000 would only be possible where 1:100,000-scale geologic maps are available. Also, calculation of landslide slope angles from the 30-meter NED and compiled 1:100,000-scale landslide maps are subject to inexactness of scale and compilation and should be considered approximate.

SOURCES OF DATA

Landslide Database

The landslide database is a GIS dataset of 45 landslide maps at 1:100,000 scale (Utah AGRC, 2006a) that were compiled by Harty (1992, 1993). These maps are a compilation of landslides from existing maps and reports by numerous authors. The maps do not show all landslides in Utah because many areas have not been mapped for landslides. Subsequent 1:24,000 to 1:100,000 and more detailed mapping has identified additional landslides; the database is being updated by the Utah Geological Survey (UGS).

Landslides in the database were grouped into different landslide map units by Harty (1992, 1993), including deep landslides (depth to surface of rupture generally greater than 10 feet), shallow landslides (depth to surface of rupture generally less than 10 feet), and landslides undifferentiated from other gravity-derived deposits such as talus, colluvium, and glacial deposits. The landslide database includes approximately 14,000 mapped landslides and units including landslides, of which 5,600 are deep landslides and 1,440 are shallow landslides. The remainder of the database consists mostly of landslides undifferentiated from other gravity-derived deposits.

Only deep landslides are used in our analysis because they characterize material conditions in the geologic unit that failed. Shallow landslides are not used in our analysis because they generally involve near-surface material where the shallow surface of rupture may not reflect failure of the geologic unit. Deep landslides typically initiate on lower angle slopes than shallow landslides (Sidle and Ochiai, 2006) and provide a more conservative analysis. Units depicting landslides undifferentiated from other gravity-derived deposits are not used in our analysis because they do not actually reflect landslide slope conditions; many of these units have slope angles less than five degrees which are lower than typical angles encountered for landslides. The deep landslides used in our analysis consist of individual landslides and landslide complexes (clusters of individual slides in close proximity, including slides within slides). These individual landslides and landslide complexes are not differentiated in the database, and our average landslide slope angles apply to both.

Digital Geologic Map

The 1:500,000-scale geologic map of Utah (Hintze and others, 2000) provided the geologic data used to evaluate landslide slope angles in geologic units. The map is

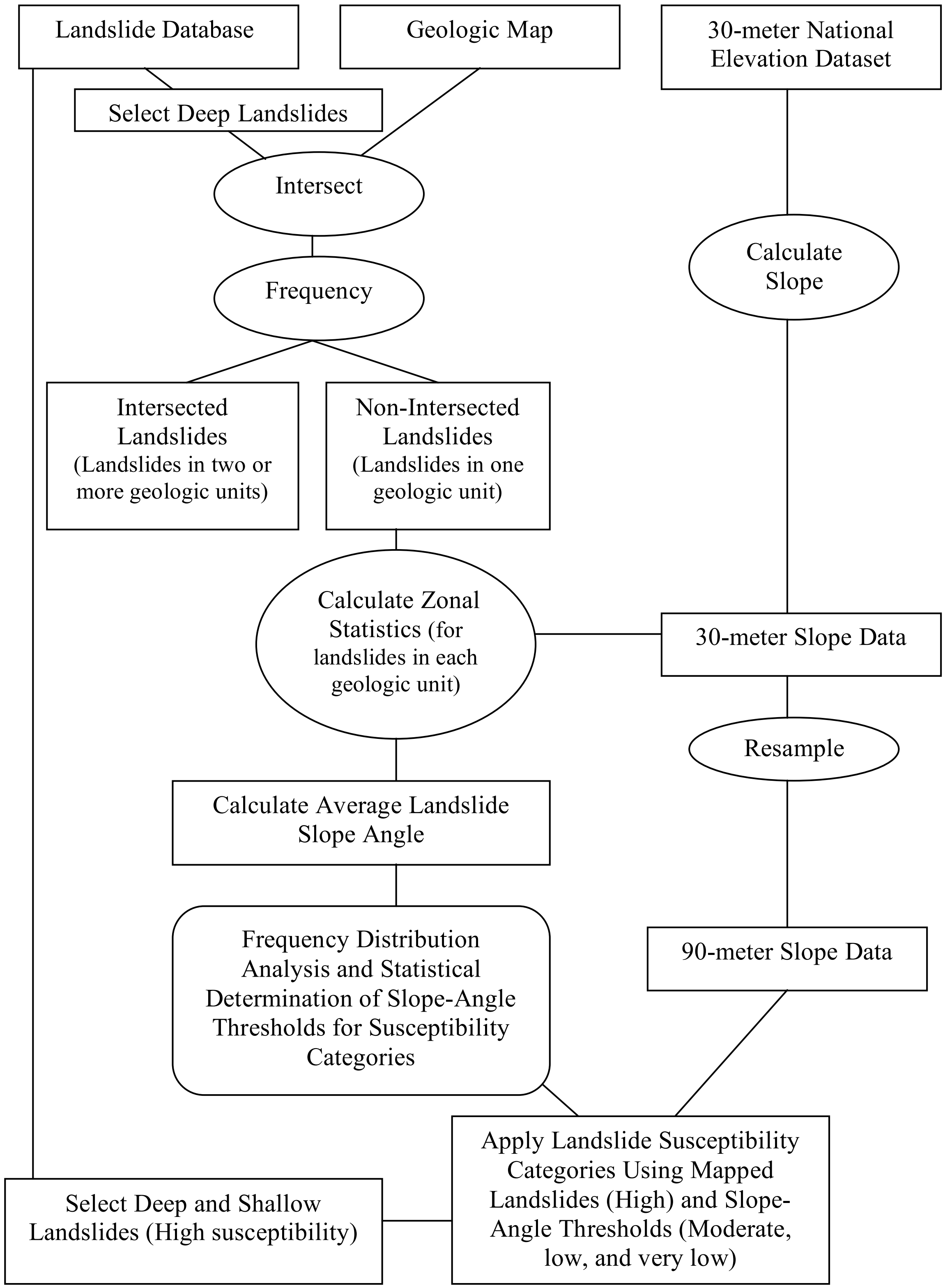

Figure 1. GIS flow chart showing source data and steps taken to produce the landslide susceptibility map. Rectangles represent GIS datasets, ovals represent GIS processes, and the rounded rectangle is a non-GIS step.

composed of 51 geologic units, and the map units, age, and formation name(s) or general lithology are shown in appendix A. Most map units are bedrock units but several unconsolidated units are also present. Many map units contain several formations within a certain age range. Even though a map unit may contain more than one formation, the map units generally contain broadly similar bedrock or unconsolidated lithologies. Landslide slope angles generally reflect the weakest, most slide-prone lithologies in units with multiple formations or lithologies.

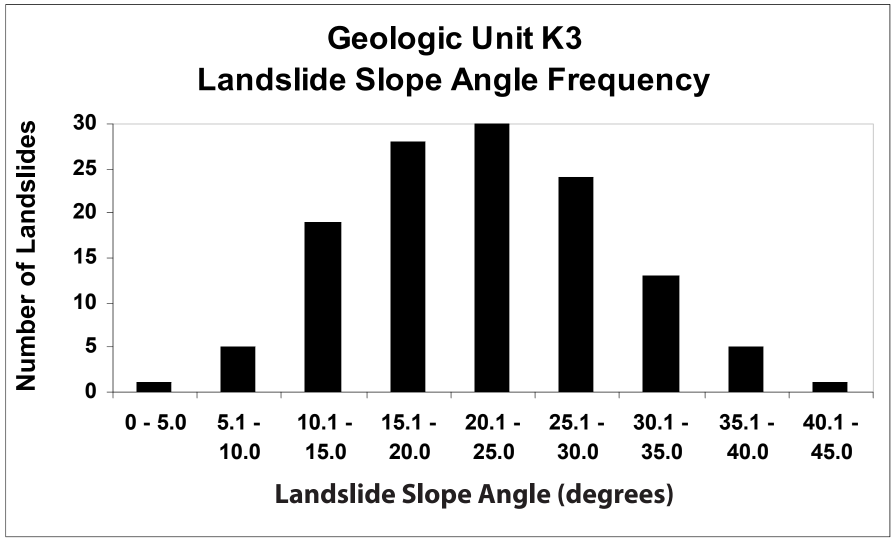

Figure 2. Landslide slope angle frequency in geologic unit K3 showing a normal distribution of landslide slope angles.

Slope Map

A statewide slope map was derived from a 30 x 30-meter NED (Utah AGRC, 2006b). A 30 x 30-meter rather than a 10 x 10-meter NED was used because the 30-meter grid size captures all landslides in the database and geologic-map units and is computationally practical statewide. The slope map is used to determine average landslide slope angles used in statistical analysis and to apply the assigned slope-angle thresholds to define susceptibility categories.

LANDSLIDE ANALYSIS

Average Landslide Slope Angle

The average landslide slope angle was calculated for landslides that lie entirely within each geologic unit using GIS operations (figure 1). Landslides that lie in two or more map units are not analyzed because they do not reflect the landslide slope in a single map unit. The average landslide slope angle in degrees is calculated by averaging the slope of all 30 x 30-meter cells within a landslide area. GIS operations produced a dataset of landslides and average slope angles in each geologic-map unit for statistical analysis. Average landslide slope angle provides a conservative measure of the angle needed for failure because landslides generally travel downslope from a steeper pre-failure angle to a flatter post-failure angle.

Frequency Analysis of Landslide Slope Angle

We analyzed landslide slope-angle frequency plots in five-degree intervals to show the average slope angle, range in slope angles, and frequency distribution. Thirty one (31) of the 51 map units have a sufficient number of landslides to yield a frequency distribution. Of the 31 units, 22 (71%) have normal distributions (figure 2). Of the remaining nine units, eight have distributions skewed to low slope angles and one unit has a non-normal distribution. The remaining 20 of the 51 units contain 10 or fewer landslides and the sample size was too small to yield a characteristic distribution shape. Not all geologic-map units contain landslides; for example, lake, marsh, and salt-flat deposits are very flat and have few or no mapped landslides.

The frequency distributions skewed to low angles contain slope angles lower than expected for landslides. Low average landslide slope angles generally result from small landslides adjacent to flat terrain (valley floors, stream terraces, or mesas). These landslides contain some 30-meter grid cells with relatively flat slope cells that yield low average slope. These apparent low-angle landslides show the limitations of the scale of the landslide source data and our method of calculating average landslide slope angle. Overall, these low-angle landslides make up a small percentage of the landslides analyzed.

The frequency analysis also shows the number of mapped landslides in each geologic unit (appendix B). The geologic units that have a large number of landslides generally contain one or more geologic formations identified by Harty (1991) as prone to producing landslides. The number of landslides in the geologic units with landslide prone formations range from 37 to 358.

Landslide Susceptibility Categories

Two steps are used to assign landslide susceptibility categories. The first step assigns mapped landslides as high susceptibility areas. Observations of landslide movement in Utah show that nearly all historically active landslides are reactivations of pre-existing landslides and these mapped landslides have the greatest potential for movement. The second step uses one and two standard-deviation breaks below the mean of normally distributed landslide slope-angles to assign slope-angle thresholds between moderate-low and low-very low categories, respectively, for each geologic unit. One standard deviation is subtracted from the mean slope angle to establish a threshold between moderate and low susceptibility. Slope angles at or above this mean-minus-one-standard-deviation threshold are assigned a moderate susceptibility and this threshold captures 82 to 100% of landslides in the geologic units. Two standard deviations are subtracted from the mean slope angle to establish another threshold between low and very low susceptibility. The range of slope angles between the one and two standard-deviation thresholds is assigned a low susceptibility. Slope angles below the mean-minus-two-standard-deviation threshold are assigned a very low susceptibility. The number of landslides, landslide slope angles, and slope-angle thresholds and susceptibility categories for each map unit are shown in appendix B.

Statistical techniques could not be used to assign susceptibility categories for all map units. Susceptibility categories for map units having non-normal, skewed distributions, or a small number of landslides are assigned using the slope-angle thresholds set for another map unit of similar age and lithology. Geologic units having a large range in landslide slope angles may have mean-minus-one and mean-minus-two-standard-deviation thresholds that are unreasonably low for deep landslides (less than 5°) in even the most slide-prone material. For these units, we establish more reasonable thresholds using thresholds for another map unit of similar age and lithology. The substitute slope-angle thresholds are shown in appendix B.

LANDSLIDE SUSCEPTIBILITY MAP

GIS operations are used to apply susceptibility categories to the 1:500,000-scale map and show susceptibility categories with different colors. The high-susceptibility category includes both deep and shallow mapped landslides. Shallow landslides were not included in the statistical analysis to determine susceptibility, but they are prone to reactivation similar to deep landslides. We applied moderate, low, and very low susceptibility categories using 90 x 90-meter cells on the slope map and assigned slope-angle thresholds for each map unit. Initially we attempted application using the 30 x 30-meter cells used in statistical analysis, but this was computationally impractical. The larger cell size makes no visual difference in the susceptibility map at the 1:500,000 scale. The moderate, low, and very low categories are based on analysis to deep landslides and these categories estimate only the susceptibility to deep landslides. However, because shallow landsides generally occur on steeper slope angles, they are captured indirectly.

A description of the landslide susceptibility categories follows.

- High susceptibility – Areas of existing shallow and deep landslides. Slope angle and geologic unit are not considered in this category.
- Moderate susceptibility – Areas that have slopes prone to landsliding based on observed landslide slope angles. The category includes slopes greater than 7° (12%) to greater than 18° (32%) depending on the geologic unit.
- Low susceptibility – Areas that have slopes that may produce landslides. The category includes slopes from 5 to 7° (9–12%) for the lower slope-angle threshold ranging up to 13 to 18° (23–32%) for the upper slope-angle threshold depending on the geologic unit.
- Very low susceptibility – Areas that are unlikely to produce landslides. The category includes slopes less than 5° (9%) to less than 7° (12%) depending on the geologic unit.

Map Use and Limitations

The map shows landslide susceptibility on a relative scale based on existing landslides and slope-angle thresholds for different geologic units. The relative scale shows areas that are more hazardous than others. The low and very low susceptibility categories do not indicate that landslides have not or cannot occur in these areas. Human activities can reduce stability, alter ground-water levels, and trigger landslides on any slope. The susceptibility categories do not indicate how far a landslide will travel or where the landslide material will be deposited. Small, localized areas of higher or lower landslide susceptibility are likely within the susceptibility categories but identification of these areas is precluded due to the statewide scale of the map. A limitation of our map is the possibility that other causative factors not considered in our analysis may result in landsliding. Climate is one of these factors, and dry climates in western and southeastern Utah greatly reduce landslide occurrences even in susceptible units. The map cannot be used to determine slope stability for any individual structure or site. This map is not intended for use at scales other than the published scale and such use may result in erroneous conclusions regarding landslide hazard.

The map is designed for regional planning use to determine areas where local landslide hazards may exist and where more detailed planning maps and landslide studies are needed, particularly in areas of high and moderate susceptibility. Local detailed landslide hazard studies may yield different landslide boundaries than shown on the map.

SUMMARY

We produced a statewide landslide susceptibility map using a landslide database and geology and slope maps. Four landslide susceptibility categories are shown on the map. The high susceptibility category consists of mapped landslides because most historical landslides are reactivations of pre-existing landslides. Outside of mapped landslides, the slope angles on which landslides occur in geologic units are used to determine landslide susceptibility categories. Slope-angle thresholds for moderate, low, and very low susceptibility categories were assigned using statistical breaks of average landslide slope-angle frequency distributions for each geologic unit. Where statistical breaks could not be applied, slope-angle thresholds were assigned using thresholds established for other map units of similar age and composition. A GIS was used to store, sort, analyze, and display information.

The landslide susceptibility map is a generalized statewide map that shows landslide areas and areas of relative landslide potential. The map is designed for general planning to identify areas where local landslide hazard mapping is needed for land-use planning. In areas of high and moderate susceptibility the UGS recommends more detailed geologic-hazard mapping and landslide studies to address the landslide hazard. Our analysis relies on existing landslides, geologic units, and slope. Other factors not considered in our analysis may locally affect landslide susceptibility.

ACKNOWLEDGMENTS

Ryan Pietramali provided funding for this project from the Utah Division of Homeland Security under the federal Pre-Disaster Mitigation Grant Program. Jerry DeGraff provided helpful suggestions on scoping this study and on landslide susceptibility analysis. Brennan Young assisted with the frequency analysis. Improvements to early drafts of this map and text document resulted from reviews by Gary Christenson and Francis Ashland.

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APPENDIX A

GEOLOGIC UNIT EXPLANATIONS

(From Hintze and others, 2000)

Map Unit	**Age**	**Explanation**
Qa	Quaternary	surficial alluvium and colluvium
Qao	Quaternary	surficial older alluvium and colluvium
Qe	Quaternary	surficial eolian deposits
Qg	Quaternary	surficial glacial deposits
Ql	Quaternary	surficial Lake Bonneville deposits
Qm	Quaternary	surficial marsh deposits
Qs	Quaternary	surficial mud and salt flat deposits
Qls	Quaternary	surficial landslide deposits
Qb	Quaternary	volcanic rocks—mostly basalt
Qr	Pliocene	volcanic rocks—rhyolite
QT	Miocene-Pleistocene	high-level alluvial deposits
Tpb	Pliocene	volcanic rocks—mostly basalt
Tpr	Pliocene	volcanic rocks—rhyolite
Tmv	Miocene	volcanic rocks
Tmr	Miocene	volcanic rocks—rhyolite
Tmb	Miocene	volcanic rocks—basalt, rhyolite, andesite, tuffaceous rocks
Tma	Miocene	volcanic rocks—andesite
T5	Miocene-Pliocene	Sevier River, Browns Park, Castle Valley Formations
T4	Oligocene-Pliocene	Salt Lake Formation and other valley-filling alluvial, lacustrine, and volcanic units
Tov	Oligocene	volcanic rocks
Tvu	Tertiary	volcanic rocks—Tertiary
Ti	Tertiary	intrusive rocks—Tertiary
T3	Eocene-Oligocene	Duchesne River, Uinta, Bridger, Crazy Hollow, and other Formations
T2	Eocene	Green River, Fowkes, and other Formations
T1	Cretaceous-Eocene	Wasatch, Colton, Flagstaff, Claron, White Sage, and other Formations
TK	Paleocene-Cretaceous	Evanston, North Horn, Currant Creek, Canaan Peak, and other Formations
K3	Cretaceous	Mesaverde Group, Price River, Kaiparowits, Echo Canyon, and other Formations
K2	Cretaceous	Indianola, Mancos, Frontier, Straight Cliffs, Iron Springs, and other Formations
K1	Cretaceous	Dakota, Cedar Mountain, Kelvin, and other Formations
Ji	Jurassic	intrusive rocks—Jurassic
J2	Jurassic	Morrison Formation
J1	Jurassic	Summerville, Entrada, Carmel, Arapien, Twin Creek, and other Formations
Jg	Jurassic	Glen Canyon Group (Navajo, Kayenta, Wingate, Moenave Formations) and Nugget Formation
Tr2	Triassic	Chinle, Ankareh Formations
Tr1	Triassic	Moenkopi, Dinwoody, Woodside, Thaynes, and other Formations
P2	Permian	Kaibab, Toroweap, Park City, and other Formations
P1	Permian	Cedar Mesa, Diamond Creek, Arcturus, and other Formations
PIP	Pennsylvanian-Permian	Oquirrh Group, Wells, Weber, Ely, Callville, and other Formations
IP	Pennsylvanian	Morgan, Round Valley, Honaker Trail, Paradox, Ely, and other Formations
M3	Mississippian	Chainman, Manning Canyon, Doughnut, and other Formations
M2	Mississippian	Great Blue, Humbug, Deseret, and other Formations
M1	Mississippian	Redwall, Madison, Gardison, Lodgepole, and other Formations
D	Devonian	Devonian Formations
S	Silurian	Laketown and Bluebell Dolomite
O	Ordovician	Fish Haven, Swan Peak, Garden City, Eureka, and other Formations

C3	Cambrian	St. Charles, Nounan, Bloomington, and other Upper Cambrian Formations
C2	Cambrian	Middle Cambrian Formations
C1	Cambrian	Prospect Mountain, Tintic, Ignacio, Geertsen Canyon, and other Formations
PCs	Proterozoic	sedimentary and metasedimentary formations
PCi	Precambrian	intrusive rocks—Precambrian
PCm	Precambrian	metamorphic rocks

APPENDIX B

GEOLOGIC MAP UNITS AND LANDSLIDE SUSCEPTIBILITY SLOPE ANGLE THRESHOLDS

Map Unit	Number of Landslides	Mean[1] Landslide Angle (degrees)	1 σ[1] (degrees)	Substitute Threshold Unit	Moderate[4] Susceptibility (degrees)	Low[4] Susceptibility (degrees)	Very Low[4] Susceptibility (degrees)
Qa	277	11.4	7.2	Qao[2, 3]	≥ 8	<8 - ≥ 4	<4
Qao	29	13.0	4.7	-	≥ 8	<8 - ≥ 4	<4
Qe	5	-	-	Qao[2, 3]	≥ 8	<8 - ≥ 4	<4
Qg	114	16.1	7.1	Qao[2, 3]	≥ 8	<8 - ≥ 4	<4
Ql	149	10.5	5.8	Qao[2, 3]	≥ 8	<8 - ≥ 4	<4
Qm	0	-	-	Qao[2, 3]	≥ 8	<8 - ≥ 4	<4
Qs	3	-	-	Qao[2, 3]	≥ 8	<8 - ≥ 4	<4
Qls	39	14.8	5.1	-	≥ 10	<10 - ≥ 5	<5
Qb	0	-	-	Tmv[2, 3]	≥ 15	<15 - ≥ 9	<9
Qr	1	-	-	Tmv[2, 3]	≥ 15	<15 - ≥ 9	<9
QT	6	-	-	Qao[2, 3]	≥ 8	<8 - ≥ 4	<4
Tpb	0	-	-	Tmv[2, 3]	≥ 15	<15 - ≥ 9	<9
Tpr	0	-	-	Tmv[2, 3]	≥ 15	<15 - ≥ 9	<9
Tmv	281	20.5	5.6	-	≥ 15	<15 - ≥ 9	<9
Tmr	0	-	-	Tmv[2, 3]	≥ 15	<15 - ≥ 9	<9
Tmb	3	-	-	Tmv[2, 3]	≥ 15	<15 - ≥ 9	<9
Tma	0	-	-	Tmv[2, 3]	≥ 15	<15 - ≥ 9	<9
T5	10	-	-	T4[2, 3]	≥ 10	<10 - ≥ 6	<6
T4	29	13.8	3.9	-	≥ 10	<10 - ≥ 6	<6
Tov	197	12.8	3.7	-	≥ 9	<9 - ≥ 5	<5
Tvu	43	16.1	7.1	Tov[3]	≥ 9	<9 - ≥ 5	<5
Ti	16	22.3	4.5	-	≥ 18	<18 - ≥ 13	<13
T3	27	14.4	5.2	T2[3]	≥ 9	<9 - ≥ 5	<5
T2	23	14.1	4.5	-	≥ 10	<10 - ≥ 5	<5
T1	231	18.6	8.5	TK[3]	≥ 10	<10 - ≥ 5	<5
TK	318	19.0	7.2	-	≥ 12	<12 - ≥ 5	<5
K3	125	21.8	7.4	-	≥ 14	<14 - ≥ 7	<7
K2	358	17.5	7.8	TK[3]	≥ 10	<10 - ≥ 5	<5
K1	124	14.6	7.2	TK[3]	≥ 7	<7 - ≥ 5	<5
Ji	0	-	-	Ti[2, 3]	≥ 18	<18 - ≥ 13	<13
J2	79	13.2	7.9	K2[2], TK[3]	≥ 10	<10 - ≥ 5	<5
J1	126	15.5	7.5	TK[3]	≥ 8	<8 - ≥ 5	<5

Map Unit	Number Of Landslides	Mean[1] Landslide Angle (degrees)	1 σ[1] (degrees)	Substitute Threshold Unit	Moderate[4] Susceptibility (degrees)	Low [4] Susceptibility (degrees)	Very Low[4] Susceptibility (degrees)
Jg	63	15.7	13.8	K2[2, 3]	≥ 10	<10 - ≥ 5	<5
Tr2	153	14.0	6.3	TK[3]	≥ 8	<8 - ≥ 5	<5
Tr1	37	14.9	6.3	TK[3]	≥ 9	<9 - ≥ 5	<5
P2	4	-	-	M2[2, 3]	≥ 12	<12 - ≥ 5	<5
P1	25	14.8	8.8	PIP[2, 3]	≥ 14	<14 - ≥ 6	<6
PIP	70	22.0	7.9	-	≥ 14	<14 - ≥ 6	<6
IP	10	-	-	PIP[2, 3]	≥ 14	<14 - ≥ 6	<6
M3	46	18.1	6.6	-	≥ 12	<12 - ≥ 5	<5
M2	54	20.7	8.5	M3[3]	≥ 12	<12 - ≥ 5	<5
M1	3	-	-	M2[2], M3[3]	≥ 12	<12 - ≥ 5	<5
D	1	-	-	M2[2], M3[3]	≥ 12	<12 - ≥ 5	<5
S	0	-	-	M2[2], M3[3]	≥ 12	<12 - ≥ 5	<5
O	3	-	-	M2[2], M3[3]	≥ 12	<12 - ≥ 5	<5
C3	6	-	-	M2[2], M3[3]	≥ 12	<12 - ≥ 5	<5
C2	30	20.6	5.9	-	≥ 15	<15 - ≥ 9	<9
C1	29	20.6	7.5	-	≥ 13	<13 - ≥ 6	<6
PCs	60	17.5	6.7	C1[3]	≥ 11	<11 - ≥ 6	<6
PCi	0	-	-	PCs[2], C1 [3]	≥ 11	<11 - ≥ 6	<6
PCm	44	23.2	5.9	PCs[2], C1 [3]	≥ 11	<11 - ≥ 6	<6

[1] *The mean landslide angle and 1 σ were not calculated for map units with 10 or fewer landslides.*
[2] *Substitute used for moderate susceptibility category.*
[3] *Substitute used for low and very low susceptibility categories.*
[4] *The final susceptibility slope angle threshold is rounded to the nearest degree.*

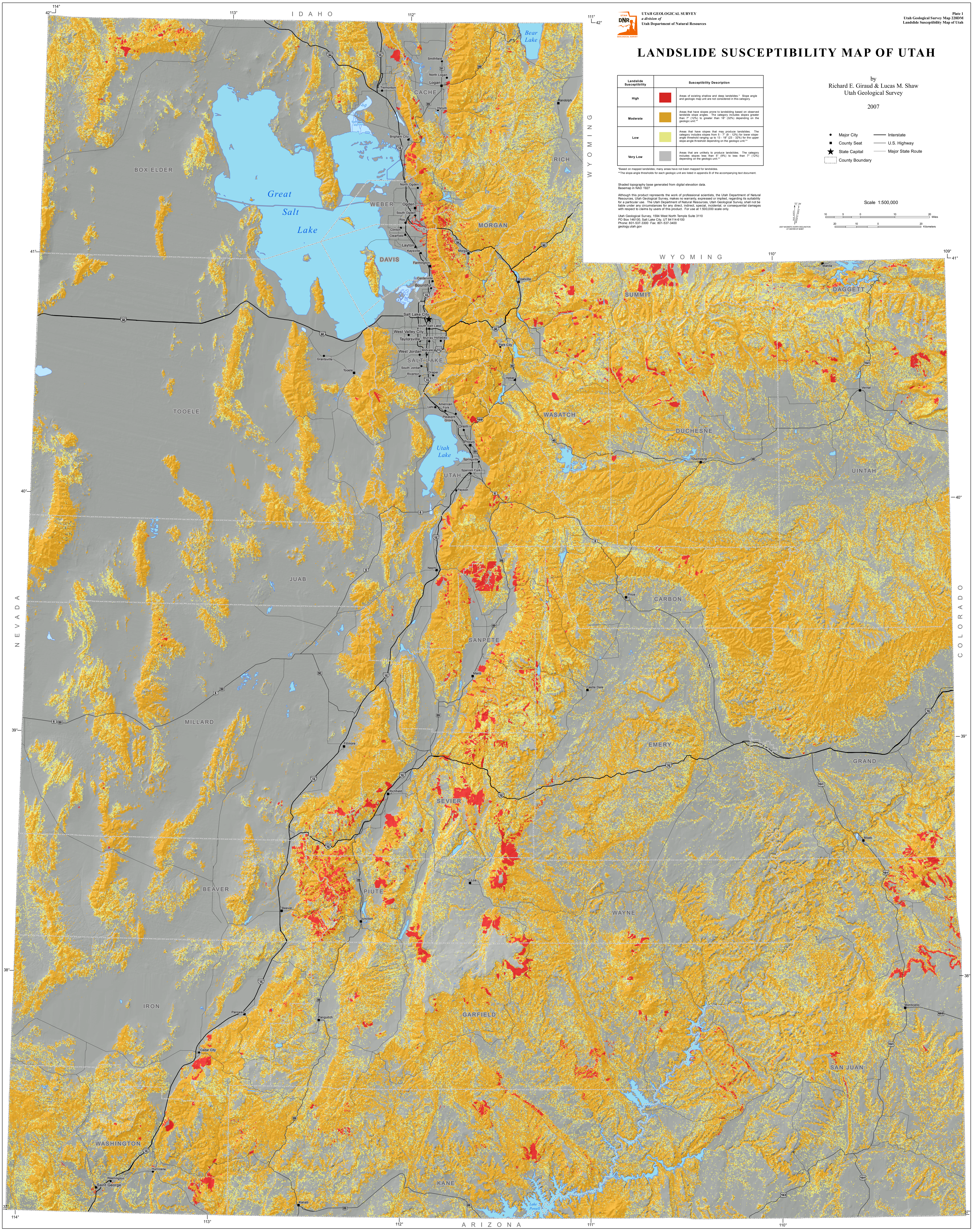
UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources

Plate 1
Utah Geological Survey Map 228DM
Landslide Susceptibility Map of Utah

LANDSLIDE SUSCEPTIBILITY MAP OF UTAH

by
Richard E. Giraud & Lucas M. Shaw
Utah Geological Survey

2007



Landslide Susceptibility	Susceptibility Description	
High		Areas of existing shallow and deep landslides.* Slope angle and geologic map unit are not considered in this category.
Moderate		Areas that have slopes prone to landsliding based on observed landslide slope angles. The category includes slopes greater than 7° (12%) to greater than 18° (32%) depending on the geologic unit.**
Low		Areas that have slopes that may produce landslides. The category includes slopes from 5 - 7° (9 - 12%) for lower slope-angle threshold ranging up to 13 - 18° (23 - 32%) for the upper slope-angle threshold depending on the geologic unit.**
Very Low		Areas that are unlikely to produce landslides. The category includes slopes less than 5° (9%) to less than 7° (12%) depending on the geologic unit.**

*Based on mapped landslides; many areas have not been mapped for landslides.
**The slope-angle thresholds for each geologic unit are listed in appendix B of the accompanying text document.

Major City
County Seat
State Capital
County Boundary
Interstate
U.S. Highway
Major State Route

Shaded topography base generated from digital elevation data.
Basemap in NAD 1927

Utah Geological Survey, 1594 West North Temple Suite 3110
PO Box 146100, Salt Lake City, UT 84114-6100
Phone: 801-537-3300 Fax: 801-537-3400
geology.utah.gov

12° 24'
TRUE NORTH
MAGNETIC NORTH
2007 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

Scale 1:500,000

10 5 0 10 20 Miles

20 10 0 20 Kilometers