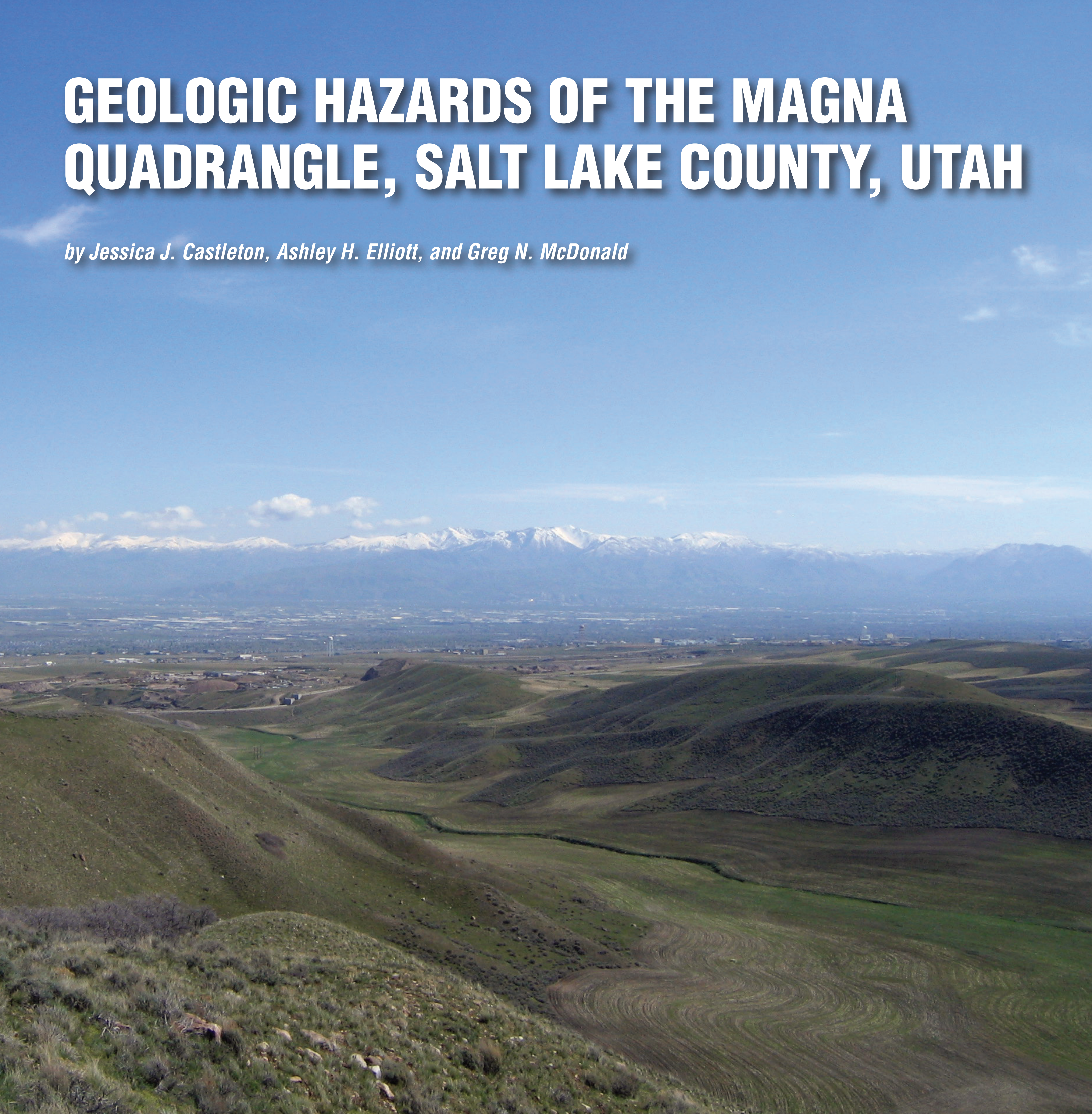
GEOLOGIC HAZARDS OF THE MAGNA QUADRANGLE, SALT LAKE COUNTY, UTAH

by Jessica J. Castleton, Ashley H. Elliott, and Greg N. McDonald



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Cover photo: *Harkers Canyon. View northeast, towards Magna and West Valley City, Utah, April 27, 2009.*

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Chapter 1
Introduction

This chapter is part of Utah Geological Survey Special Study 137, *Geologic Hazards of the Magna Quadrangle, Salt Lake County, Utah.*

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Chapter 1: Introduction

ABSTRACT

The Magna quadrangle, in the western part of the Salt Lake Valley, is expected to experience a significant population increase in the next several decades. As urbanization expands into areas less suited for development, geologic hazards become of increasing concern in the planning, design, and construction of new facilities. This geologic-hazard study of the Magna quadrangle incorporates geologic, hydrologic, soil, and geotechnical information and is intended to assist city and county government agencies with land-use planning and regulation by identifying where geologic hazards may exist, and where detailed, site-specific, geotechnical/geologic-hazard investigations are necessary. Geotechnical engineers, engineering geologists, design professionals, building officials, developers, and the general public will find this study useful to identify the type and location of geologic hazards that may affect existing and future development.

This study provides maps and information for 10 geologic hazards. Historically, the most widespread and frequent geologic hazard in the Magna quadrangle is flooding. Flooding is of special concern because it can quickly become life threatening. Landslides and rock falls are of increasing concern as development moves into hillslope areas. Large earthquakes are rare events in the Magna quadrangle, but the hazards associated with them (mainly ground shaking, surface fault rupture, and liquefaction) have the greatest potential for producing catastrophic property damage, economic disruption, and loss of life of any hazard in the study area. The remaining hazards are typically localized in nature and are rarely life threatening (except for indoor radon). However, they are potentially costly when not recognized and properly accommodated in project planning and design.

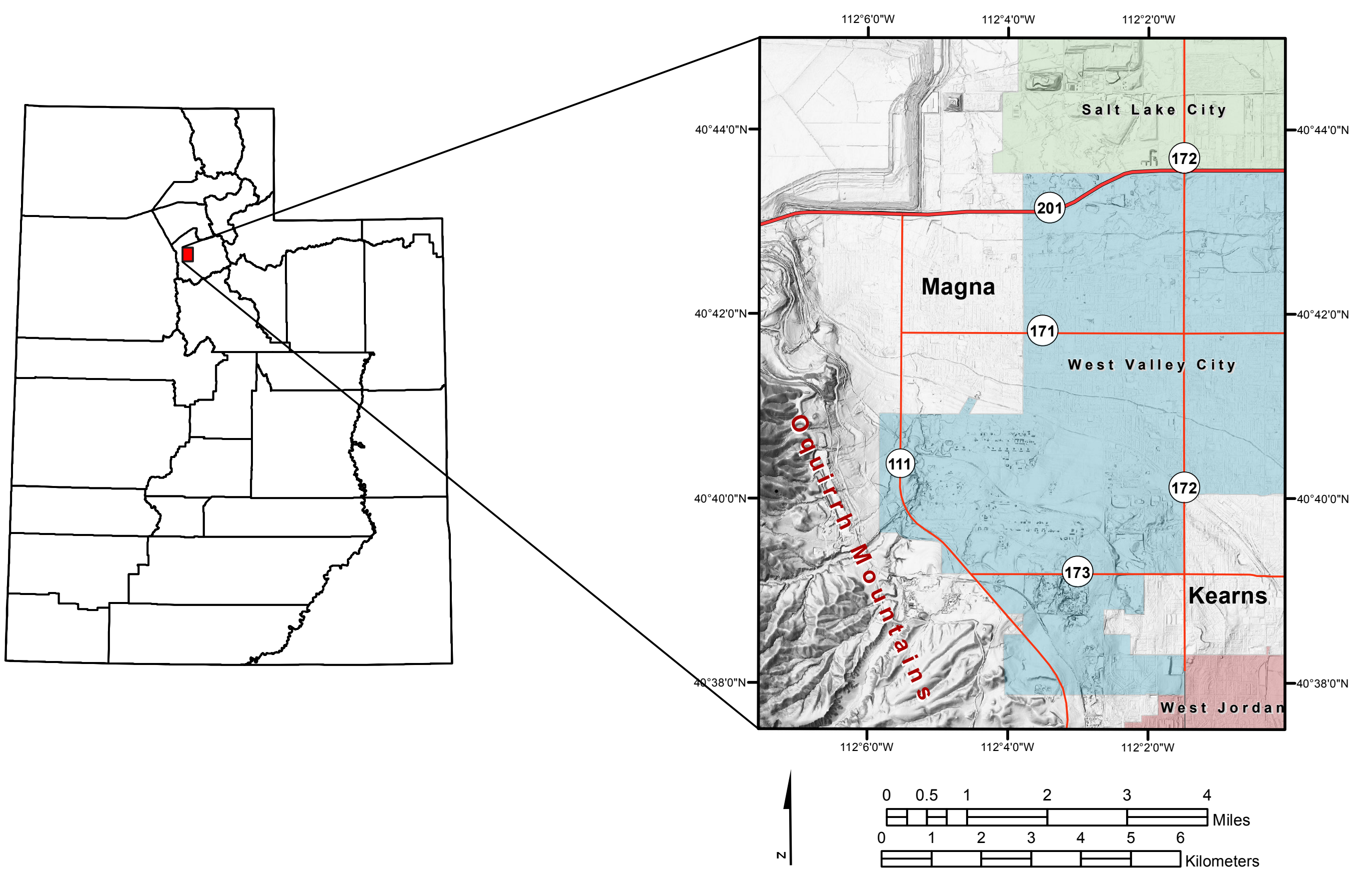

Figure 1.1. *Index map of the Magna quadrangle showing principal geographic features including boundaries of cities and towns (unshaded areas are unincorporated Salt Lake County, including Magna and Kearns) and major transportation routes.*

PURPOSE

This study provides geotechnical engineers, engineering geologists, design professionals, building officials, developers, and the general public with information on the types and locations of geologic hazards that may affect existing and future development in the Magna quadrangle (figure 1.1). We compiled the data for this study at a scale of 1:24,000 (1 inch = 2000 feet) using a Geographic Information System (GIS). The maps accompanying this report (plates 1–10 and the associated GIS files) are at the same scale. The maps are designed as an aid for general planning to indicate where more detailed, site-specific geotechnical/geologic-hazard investigations are necessary. The maps should not be enlarged for use at scales larger than 1:24,000, and are not a substitute for site-specific geotechnical/geologic-hazard investigations. The maps are based on limited geologic and geotechnical data. The quality of each maps depends on the quality of these data, which vary throughout the study area. Consequently, special-study-area boundaries shown on the maps are approximate and subject to change with additional information. Small, localized areas of geologic hazards may exist in the study area, but their identification was precluded due to limitations of either data availability or map scale.

We recommend performing a site-specific geotechnical/geologic-hazard investigation for development at all locations in the study area. Such investigations can resolve uncertainties inherent in the maps and help ensure safety by identifying the need for special engineering designs or hazard-reduction and/or construction techniques.

PREVIOUS WORK

The Magna quadrangle is in western Salt Lake Valley within 30 miles (48 kilometers [km]) of downtown Salt Lake City, and is expected to see increasing growth in the coming decades. As the valley's population grows, urbanization will increase, therefore, timely geologic information early in the planning and design process is critical to avoid or reduce risk from geologic hazards. Recognizing that fact, Christenson and Shaw (2008) compiled existing geologic-hazard investigations for the Wasatch Front into a GIS database. Their maps include the Magna quadrangle and present information on debris flow, surface-fault-rupture, landslide, and liquefaction hazards. Other previous geologic-hazards investigations that encompass the Magna quadrangle include investigations of :

- the West Valley fault zone (Keaton and Currey, 1993; Keaton and others, 1993),
- earthquake site conditions (McDonald and Ashland, 2008),
- earthquake hazards associated with a scenario magnitude 7 earthquake on the Salt Lake City segment of the Wasatch fault zone (including ground shaking, surface fault rupture, liquefaction, earthquake-induced landslides, and other geologic hazards) (Solomon and others, 2004),
- liquefaction (Anderson and others, 1994; Bartlett and others, 2005; Bartlett and others, 2006; Olsen and others, 2007; Hinckley, 2010), and
- radon-hazard potential (Black, 1996).

Because growth in the Magna quadrangle is expected to continue, there is a need for accurate, up-to-date information about geologic hazards in the area. Recent geologic mapping (Solomon and others, 2007) and geotechnical/geologic-hazard investigations have greatly increased our understanding of the area's geology and hazards.

SCOPE OF WORK

The scope of work for this study consisted of:

1. identifying and reviewing geologic, hydrologic, and soils information available for the study area,
2. digitizing relevant geologic, hydrologic, and soils information not already available in digital format,
3. compiling a new digital geotechnical database incorporating test data and other information from geotechnical/geologic-hazard reports on file with municipalities in the study area,
4. field checking as necessary to refine geologic-hazard maps derived from the basic geologic, hydrologic, soils, and geotechnical information,
5. preparing text documents that describe each geologic hazard in detail.

The products of this study are 10, 1:24,000-scale, geologic-hazard maps for the Magna quadrangle (plates 1 to 10) and accompanying text documents (including text for ground-shaking hazards that are not mapped due to extensive previous investigations and maps of this hazard in the quadrangle). Each map covers a different geologic hazard, and the accompanying text document provides background information on the data sources used to create the map, the nature and distribution of the hazard, and possible mitigation measures.

We compiled the data used in this study from a wide variety of sources. Principal sources included (1) recent geologic mapping of the Magna quadrangle (Solomon and others, 2007), (2) data from the U.S. Natural Resources Conservation Service (NRCS) *Soil Survey Geographic (SSURGO) Database for Salt Lake Valley Area, Salt Lake County, Utah* (NRCS, 2006), and (3) the results of geotechnical/geologic-hazard investigations conducted in the quadrangle and on file with municipalities

Table 1.1. *Principal communities, partially or completely within the Magna quadrangle, ranked in order of 2000 Census population. Where available, 2009 population estimates are given (U.S. Census Bureau, 2010).*

Community	2000 Census Population	Estimated 2009 Population
Salt Lake City	181,743	181,171
West Valley City	108,896	125,093
West Jordan	68,336	104,915
Kearns	33,659	not available
Magna	22,770	not available

(table 1.1) (see the appropriate text document for references).

SETTING

The Magna quadrangle includes the unincorporated town of Magna (in its entirety) as well as portions of Salt Lake City, West Valley City, West Jordan, and the unincorporated town of Kearns (figure 1.1). Table 1.1 ranks these communities in order of their 2000 Census population, and where available, gives their estimated 2009 population, reported in 2010 (at the time of this publication, 2010 Census results were not yet available). Although the Magna quadrangle includes only portions of most of these communities, table 1.1 demonstrates the expected growth in the area (with the exception of Salt Lake City).

Principal transportation routes crossing the study area include State Route (SR) 201, the east-west route connecting the quadrangle with downtown Salt Lake City; SR 111, a north-south road along the eastern boundary of the Oquirrh Mountains; SR 171 and 173, which connect SR 111 to Interstate 215 and farther east to Interstate 15; and SR 172, a north-south road near the eastern edge of the quadrangle (figure 1.1).

Elevations in the quadrangle range from approximately 6240 feet (1902 meters[m]) in the Oquirrh Mountains near the southwestern end of the quadrangle, to 4215 feet (1285 m) near Lee Creek in the northern end of the quadrangle. The study area is characterized by moderate precipitation, large daily temperature changes, cold damp winters, and warm dry summers. Average annual precipitation at the Garfield weather station (less than 5 miles [8 km]) northwest of Magna, and at approximately the same elevation) is 17.15 inches (43.56 centimeters [cm]) from November 1, 1924, to December 31, 2009 (Western Regional Climate Center, 2010). Average annual precipitation at the Salt Lake International Airport weather station (about 12 miles [19 km] northeast of Magna, and at approximately the same elevation) is 15.62 inches (39.67 cm) from January 1, 1948, to December 31, 2009 (Western Regional Climate Center, 2010). Precipitation in the Oquirrh Mountains bordering the Magna quadrangle on the west, is more than five inches greater (based on Western Regional Climate Center [2010] data for the Bingham Canyon weather station from December 1, 1940, to October 31, 1974). Most precipitation comes in the form of storms that move through the valley from the north Pacific Ocean during fall, winter, and spring, with winter precipitation falling as snow. Summer temperatures at lower elevations in the study area commonly exceed 90° Fahrenheit (°F) (32.2° Celsius [°C]); the long-term average (11/1/1924 to 12/31/2009) maximum temperature for July at the Garfield weather station is 91.5°F (33.1°C); the long-term average (1/1/1948 to 12/31/2009) maximum temperature for July at the Salt Lake International Airport weather station is 92.8°F (33.8°C) (Western Regional Climate Center, 2010).

The dominant vegetation on the valley floor includes various types of perennial grasses. However, in the northern portion of the quadrangle, where shallow groundwater is present and frequent flooding is possible, greasewood and Russian olive trees dominate. As the elevation rises along valley margins, vegetation changes to a variety of shrubs, including sagebrush.

GEOLOGY

Salt Lake Valley occupies a structural basin in the Basin and Range physiographic province (Stokes, 1977). The basin is bounded by the Wasatch Range on the east and the Oquirrh Mountains on the west. The Wasatch Range consists of a complex sequence of sedimentary, metamorphic, and igneous rocks ranging in age from Precambrian to Tertiary. The range marks the western boundary of the Middle Rocky Mountains physiographic province (Stokes, 1977). The Oquirrh Mountains are composed primarily of Pennsylvanian and Permian sedimentary rocks and Tertiary sedimentary and volcanic rocks. In addition, hydrothermal solutions introduced in conjunction with Tertiary intrusive activity caused the precipitation of ore and gangue minerals in areas in and surrounding the intrusives (Tooker, 1999), making the Oquirrh Mountains rich in valuable ore. The Oquirrh Mountains are home to the Bingham Canyon Mine, one of the largest copper mines in the world. The bedrock of the Wasatch Range and Oquirrh Mountains were deformed by Late Cretaceous to early Tertiary contractional faulting and folding of the Sevier orogeny (e.g., Willis; 1999; DeCelles, 2006; Schelling and others, 2007), extensional faulting during late Eocene to middle Miocene “collapse” (Constenius, 1996; Constenius and others, 2003), and middle Miocene to recent Basin-and-Range faulting (Zoback and others, 1981; Smith and Bruhn, 1984). The Wasatch fault zone (at the western base of the Wasatch Range), the West Valley fault zone (in the north-central part of the valley), and the Oquirrh fault zone (at the western base of the Oquirrh Mountains) are the most prominent and youngest features associated with Basin-and-Range extensional faulting.

The Salt Lake Valley is within the Great Basin, an area of internal drainage for much of the past 15 million years. The surficial sediments of the valley were mostly deposited by latest Pleistocene Lake Bonneville (Oviatt and others, 1992; Oviatt and others, 1999), a large pluvial lake that covered much of northwestern Utah and adjacent parts of Idaho and Nevada (Gilbert, 1890). The lake began to rise above levels comparable to those of Great Salt Lake after about 35,000 calendar years ago (CRONUS-Earth Project, 2005), and was in part contemporaneous with the most recent glacial advance, the Pinedale glaciation (Lips and others, 2005). Four major shorelines, associated with transgressive (rising) and regressive (lowering) phases of Lake Bonneville, are recognized in Salt Lake Valley. All of these shorelines, Stansbury, Bonneville, Provo, and Gilbert, are present within the Magna quadrangle. The earliest shoreline, the Stansbury, was formed about 27,000 to 24,000 years ago during a transgressive phase of the lake. The lake reached its highest level about 18,300 years ago, forming the Bonneville regional shoreline, evident in the southern portion of the Magna quadrangle as the highest bench on the valley margin. The level of the Bonneville shoreline was controlled by an overflow threshold at an elevation of approximately 5092 feet (1552 m) near Zenda in southern Idaho. About 17,400 years ago, overflow and rapid erosion at the Zenda threshold resulted in catastrophic lowering of the lake by 340 feet (104 m) (Jarrett and Malde, 1987) in less than one year (O’Conner, 1993). Lake Bonneville then stabilized at a new lower threshold near Red Rock Pass, Idaho, and the Provo regional shoreline formed on the lower slopes of the Oquirrh Mountains. About 14,600 years ago, a warming climate induced further lowering of the lake level (Godsey and others, 2005), and by about 13,500 years ago, the level of Lake Bonneville had fallen below the elevation of present Great Salt Lake (Currey and others, 1988; Godsey and others, 2005). Between 12,500 to 11,500 years ago, a minor expansion of Lake Bonneville formed the Gilbert shoreline (Oviatt and others, 2005). After the formation of the Gilbert shoreline, Lake Bonneville receded, leaving Great Salt Lake behind.

More details on the stratigraphy, structure, and geologic resources of the Magna quadrangle and additional references are included on the geologic map of the quadrangle (Solomon and others, 2007). Additionally, studies of the West Valley fault zone (Keaton and Currey, 1993; Keaton and others, 1993), the Oquirrh fault zone (Lund, 1996), and the Oquirrh Mountains (Cook, 1961; Tooker and Roberts, 1998; Tooker, 1999) contain information regarding the geology of the area.

RELATIVE IMPORTANCE OF GEOLOGIC HAZARDS

This study provides information on 10 geologic hazards in the Magna quadrangle. Not all of the hazards are of equal concern. On an annual basis, the most common and damaging geologic hazard is flooding. Major flooding examples include:

- August 2, 1922, Little Valley Wash flood that destroyed a house in Magna, killing a young boy inside,
- August 13, 1930, floods that filled 12 homes with mud (Woolley, 1946),
- August 3 and 4, 1951, floods that inundated several Magna homes,
- July 26, 1954, flooding of more than 12 homes and businesses,
- August 31, 1963, flooding that inundated several basements and caused more than $4,500 in damages (Butler and Marsell,1972), and
- the 1986 historical peak elevation (4211.85 feet [1283.77 m]) of Great Salt Lake (Harty and Christenson, 1988), within four feet of the lowest elevation of the Magna quadrangle.

Because of their wide distribution, frequent occurrence, and destructive potential, floods will undoubtedly remain the principal geologic issue in the quadrangle with which planners and others will contend in the future.

Landslides and rock falls are of increasing concern as development increases on hillsides, where development is often favored, due to scenic vistas and aesthetics. Existing landslides in the quadrangle, especially older ones, can be difficult to recognize, but their stability remains suspect and their identification and proper accommodation in project planning and design is critical to avoid slope-stability problems. Some bedrock units in the study area contain a high percentage of clay and are correspondingly weak and susceptible to landslides, especially when wet. The close correlation in the quadrangle of existing landslides with weak bedrock units provides ample warning that development on slopes underlain by landslide-susceptible bedrock must proceed with caution. Landslides are also associated with susceptible unconsolidated deposits. Conditions conducive to rock fall are present near the western boundary of the quadrangle, and damaging events are likely to increase as development moves into those areas, unless effective hazard-reduction measures are implemented.

Large, damaging earthquakes are rare events in the Magna quadrangle, but active faults in the quadrangle and surrounding area are capable of producing earthquakes of magnitude 7 or larger (Keaton and others, 1993; Lund, 1996; Solomon and others, 2004). Hazards associated with such large earthquakes (ground shaking, surface fault rupture, landslides, rock falls, and liquefaction) have the greatest potential for catastrophic property damage, economic disruption, and loss of life of any hazard in the study area. Because of their great destructive potential, the effects of large earthquakes must be reduced through land-use planning, adoption and enforcement of modern seismic building codes, and disaster preparedness planning and drills. Moderate earthquakes similar to the magnitude 5.2 Magna earthquake in 1962 are capable of causing significant property damage, and may be life threatening.

The remaining geologic hazards considered in this report are typically localized in nature, and while potentially costly when not recognized and properly accommodated in project planning and design, problems associated with them are rarely life threatening. An exception is the hazard posed by elevated levels of indoor radon. Breathing radon over time increases a person's risk of lung cancer, but effective techniques are available for reducing indoor radon levels in existing construction and preventing such levels in new construction.

ADDITIONAL INFORMATION AND GUIDELINES

In addition to the reports contained in this compilation, the Utah Geological Survey (UGS) Earthquakes and Geologic Hazards web page at http://geology.utah.gov/utahgeo/hazards/index.htm provides links to general information on geologic hazards in Utah. The web page for Consultants and Design Professionals (http://geology.utah.gov/ghp/consultants/index.htm) provides links to recommended guidelines for geotechnical/geologic-hazard investigations and reports, UGS geologic-hazard maps and reports, geologic maps, groundwater reports, historical aerial photography, and other sources of useful information. The UGS advises following the recommended guidelines when preparing site-specific engineering-geologic reports and conducting site-specific geotechnical/geologic-hazard investigations in Utah. Typically, geologic-engineering and geologic-hazard considerations would be combined in a single report, or included as part of a geotechnical report that also addresses site foundation conditions and other engineering aspects of the project.

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REFERENCES

Anderson, L.R., Keaton, J.R., Spitzley, J.E., and Allen, A.C., 1994, Liquefaction potential map for Salt Lake County, Utah, complete technical report: Utah Geological Survey Contract Report 94-9, 48 p. pamphlet, 9 plates, scales 1:24,000 and 1:48,000.

Bartlett, S.F., Ericksen, G., Leeflang, B., and Solomon, B.J., 2006, Probabilistic liquefaction potential and liquefaction-induced ground-failure maps for the urban Wasatch Front—Phase 3: Unpublished report to the U.S. Geological Survey, National Earthquake Hazards Reduction Program, Award 06HQGR0015, 158 p.

Bartlett, S.F., Olsen, M.J., and Solomon, B.J., 2005, Probabilistic liquefaction potential and liquefaction-induced ground-failure maps for the urban Wasatch Front—Phase 1: Unpublished report to the U.S. Geological Survey, National Earthquake Hazards Reduction Program, Awards 04HQGR0025 and 04HQGR0026, 197 p.

Black, B.D., 1996, Radon-hazard potential of western Salt Lake Valley, Salt Lake County, Utah: Utah Geological Survey Special Study 91, 27 p., 1 plate, scale 1:50,000.

Butler, E., and Marsell, R.E., 1972, Developing a state water plan, cloudburst floods in Utah, 1939–1969: Utah Department of Natural Resources, Division of Water Resources Cooperative-Investigations Report Number 11, 103 p., 1 plate.

Christenson, G.E., and Shaw, L.M., 2008, Geographic Information System database showing geologic-hazard special study areas, Wasatch Front, Utah: Utah Geological Survey Circular 106, 7 p., GIS data, scale 1:24,000, compact disk.

Constenius, K.N., 1996, Late Paleogene extensional collapse of the Cordilleran foreland fold and thrust belt: Geological Society of America Bulletin, v. 108, p. 20–39.

Constenius, K.N., Esser, R.P., and Layer, P.W., 2003, Extensional collapse of the Charleston-Nebo salent and its relationship to space-time variations in Cordilleran orogenic belt tectonism and continental stratigraphy, *in* Raynolds, R.G., and Flores, R.M., editors, Cenozoic systems of the Rocky Mountain region: Denver, Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists, p. 303–353.

Cook, D.R., editor, 1961, Geology of the Bingham mining district and northern Oquirrh Mountains: Utah Geological Society Guidebook to Geology of Utah 16, 145 p.

CRONUS-Earth Project, 2005, Draft sampling plan: Lake

Bonneville Shorelines Sampling Trip, July 7–10, 2005, online, http://tesla.physics.purdue.edu/cronus/bonneville_shoreline_sampling_plan.pdf [CRONUS: Cosmic-Ray Produced Nuclide Systematics on Earth Project].

Currey, D.R., Berry, M.S., Green, S.A., and Murchison, S.B., 1988, Very late Pleistocene red beds in the Bonneville Basin, Utah and Nevada [abs]: Geological Society of America Abstracts with Programs, v. 20, no. 6, p. 411.

DeCelles, P.G., 2006, Late Jurassic to Eocene evolution of the Cordilleran thrust belt and foreland basin system, western U.S.A.: American Journal of Science, v. 304, p. 105–168.

Gilbert, G.K., 1890, Lake Bonneville: U.S. Geological Survey Monograph 1, 438 p.

Godsey, H.S., Currey, D.R., and Chan, M.A., 2005, New evidence for an extended occupation of the Provo shoreline and implications for regional climate change, Pleistocene Lake Bonneville, USA: Quaternary Research, v. 62, p. 212–223.

Harty, K.M., and Christenson, G.E., 1988, Flood hazards from lakes and failure of dams in Utah: Utah Geological and Mineral Survey Map 111, 8 p. pamphlet, 1 plate, scale 1:750,000.

Hinckley, D.W., 2010, Liquefaction-induced ground displacement mapping for the Salt Lake Valley, Utah: Salt Lake City, University of Utah, M.S. thesis, 149 p.

Jarrett, R.D., and Malde, H.E., 1987, Paleodischarge of late Pleistocene Bonneville Flood, Snake River, Idaho, computed from new evidence: Geological Society of America Bulletin, v. 99, p. 127–134.

Keaton, J.R., and Currey, D.R., 1993, Earthquake hazard evaluation of the West Valley fault zone in the Salt Lake City urban area, Utah: Utah Geological Survey Contract Report 93-7, 69 p.

Keaton, J.R., Currey, D.R., and Olig, S.J., 1993, Paleoseismicity and earthquake hazards evaluation of the West Valley fault zone, Salt Lake City urban area, Utah: Utah Geological Survey Contract Report 93-8, 55 p.

Lips, E.W., Marchetti, D.W., and Gosse, J.C., 2005, Revised chronology of late Pleistocene glaciers, Wasatch Mountains, Utah [abs]: Geological Society of America Abstracts with Programs, v. 37, no. 7, p. 41.

Lund, W.R., editor, 1996, Paleoseismology of Utah, volume 6—the Oquirrh fault zone, Tooele County, Utah—Surficial geology and paleoseimicity: Utah Geological Survey Special Study 88, 64 p., 2 plates.

McDonald, G.N., and Ashland, F.X., 2008, Earthquake site conditions in the Wasatch Front urban corridor, Utah: Utah Geological Special Study 125, 41 p., 1 plate, scale 1:150,000, compact disk.

O'Conner, J.E., 1993, Hydrology, hydraulics, and geomorphology of the Bonneville Flood: Geological Society of America Special Paper 274, 83 p.

Olsen, M.J., Bartlett, S.F., and Solomon, B.J., 2007, Lateral spread hazard mapping of the northern Salt Lake Valley, Utah, for a M 7 scenario earthquake: Earthquake Spectra, v. 23, no. 1, p. 95–113.

Oviatt, C.G., Currey, D.R., and Sack, D., 1992, Radiocarbon chronology of Lake Bonneville, eastern Great Basin, USA: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 99, p. 225–241.

Oviatt, C.G., Miller, D.M., McGeehin, J.P., Zachary, C., and Mahan, S., 2005, The younger Dryas phase of Great Salt Lake, Utah, USA: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 219, no. 3-4, p. 263–284.

Oviatt, C.G., Thompson, R.S., Kaufman, D.S., Bright, J., and Forester, R.M., 1999, Reinterpretation of the Burmester Core, Bonneville basin, Utah: Quaternary Research, v. 52, p. 180–184.

Schelling, D.D., Strickland, D.K., Johnson, K.R., and Vrona, J.P., 2007, Structural geology of the central Utah thrust belt, *in* Willis, G.C., Hylland, M.D., Clark, D.L., and Chidsey, T.C., Jr., editors, Central Utah—diverse geology of a dynamic landscape: Utah Geological Association Guidebook 36, p. 1–29.

Smith, R.B., and Bruhn, R.L., 1984, Intraplate extensional tectonics of the eastern Basin-Range inferences on structural style from seismic reflection data, regional tectonics, and thermal-mechanical models of brittle-ductile deformation: Journal of Geophysical Research, v. 89, p. 5733–5762.

Solomon, B.J., Biek, R.F., and Smith, T.W., 2007, Geologic map of the Magna quadrangle, Salt Lake County, Utah: Utah Geological Survey Map 216, scale 1:24,000.

Solomon, B.J., Storey, N., Wong, I., Silva, W., Gregor, N., Wright, D., and McDonald, G.N., 2004, Earthquake-hazards scenario for a M7 earthquake on the Salt Lake City segment of the Wasatch fault zone, Utah: Utah Geological Survey Special Study 111DM, 59 p., 6 plates, scale 1:250,000, compact disk.

Stokes, W.L., 1977, Subdivisions of the major physiographic provinces in Utah: Utah Geology, v. 4, no. 1, p. 1–17.

Tooker, E.W., 1999, Geology of the Oquirrh Mountains, Utah: U.S. Geological Survey Open-File Report 99-571, 150 p.

Tooker, E.W., and Roberts, R.J., 1998, Geologic map of the Oquirrh Mountains and adjoining south and western Traverse Mountains, Tooele, Salt Lake and Utah Counties: U.S. Geological Survey Open-File Report 98-581, 2 plates, scale 1:50,000.

U.S. Natural Resources Conservation Service, 2006, Soil survey geographic (SSURGO) database for Salt Lake area, Salt Lake County, Utah: Online, http://soildatamart.nrcs.usda.gov, accessed December 2008.

U.S. Census Bureau, 2010, Population finder: Online, http://

www.census.gov, accessed August 2010.

Western Regional Climate Center, 2010, Climatological data summaries (Garfield [423097] and Salt Lake Intl AP [427598] locations): Online, http://www.wrcc.dri.edu/Climsum.html, accessed April 2010.

Willis, G.C., 1999, The Utah thrust system an overview, *in* Spangler, L.E., and Allen, C.J., editors, Geology of northern Utah and vicinity: Utah Geological Association Publication 27, p. 1–9.

Woolley, R.R., 1946, Cloudburst floods in Utah, 1850–1938: U.S. Geological Survey Water Supply Paper 994, 128 p., 23 plates.

Zoback, M.L., Anderson, R.E., and Thompson, G.B., 1981, Cainozoic evolution of the state of stress and style of tectonism of the Basin and Range Province of the western United States: Philosophical Transactions of the Royal Society of London, v. A300, p. 407–434.

Chapter 2
Earthquake Hazards

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Chapter 2: Earthquake Hazards

INTRODUCTION

An earthquake is the abrupt rapid shaking of the earth caused by sudden slippage of rocks deep beneath the earth's surface. The rocks break and slip when the accumulated elastic strain energy exceeds the rock's strength. The surface along which the rocks slip is called a fault. Motion along the fault generates and transmits seismic waves outward from the earthquake source, producing ground shaking. The consequences of an earthquake depend upon several factors, including its magnitude, depth, distance from population centers, and geologic and soil conditions at a particular site (Keller and Blodgett, 2006). Earthquakes occur without warning and can cause injury and death, major economic loss, and social disruption (Utah Seismic Safety Commission, 1995).

Earthquakes cause a wide variety of geologic hazards, including ground shaking, liquefaction and related ground failure, slope failure, surface faulting, regional and local subsidence, and various types of flooding (table 2.1). Ground shaking is the most widespread and typically most damaging earthquake hazard (Yeats and others, 1997). Strong ground shaking can last from several seconds to minutes and can be amplified (increased) or deamplified (decreased) depending on local soil and rock conditions (Reiter, 1990). Ground shaking is usually strongest near the earthquake epicenter and decreases away from that point. The type and quality of construction play a large role in determining the extent of damage caused by ground shaking.

Strong ground shaking can generate liquefaction and slope failures. Liquefaction (the temporary transformation of a

Table 2.1. *Principal earthquake hazards, expected effects, and hazard-reduction techniques (modified from Utah Seismic Safety Commission, 1995).*

<table>
<tr><th colspan="2">Hazard</th><th>Effects</th><th>Hazard-Reduction Techniques</th></tr>
<tr><td colspan="2">Ground Shaking</td><td>Damage or collapse of structures</td><td>Make structures seismically resistant, secure heavy objects</td></tr>
<tr><td colspan="2">Liquefaction (discussed in the Liquefaction section of this chapter)</td><td>Differential settlement, ground cracking, subsidence, sand blows, lateral spreads</td><td>Treat or drain soil, deep foundations, other structural design solutions</td></tr>
<tr><td rowspan="2">Slope Failure</td><td>Landsides (discussed in chapter 4)</td><td>Damage to structures, loss of foundation support</td><td>Avoid hazard, stabilize slopes, manage water use</td></tr>
<tr><td>Rock Fall (discussed in chapter 5)</td><td>Impact damage</td><td>Avoid hazard, remove unstable rocks, protect structures</td></tr>
<tr><td colspan="2">Surface Fault Rupture</td><td>Ground displacement, tilting or offset structures</td><td>Set structures back from fault traces</td></tr>
<tr><td colspan="2">Regional (Tectonic) Subsidence</td><td>Ground tilting, flooding from shoreline inundation and/or ponded groundwater, compromising proper operation of gravity-flow structures</td><td>Create buffer zones, build dikes, restrict basements, design tolerance for tilting</td></tr>
<tr><td colspan="2">Flooding</td><td>Earthquake-induced failure of dams, canals, pipelines, and other water storage or conveyance structures, with associated flooding</td><td>Flood-proof or strengthen structures, elevate buildings, avoid construction in potential flood areas</td></tr>
</table>

saturated cohesionless soil into a fluid accompanying earthquake ground shaking) occurs in areas of shallow groundwater and sandy soils (Reiter, 1990). Liquefaction can cause a variety of ground failure. Slope failures, including rock falls and landslides, are common in steep terrain during moderate and large earthquakes.

Surface faulting commonly accompanies large earthquakes (greater than magnitude 6.5). The rupture may affect a zone tens to hundreds of feet wide and several miles long. Little can be done from a design perspective to protect structures or other facilities from the direct effects of surface fault rupture. Subsidence due to tilting of the ground surface on the downdropped side of a fault during a large surface-faulting earthquake can affect large areas extending miles from the surface trace of the fault. Tilting of the ground surface may compromise gravity-flow structures such as wastewater-treatment plants and sewer lines. Tilting may also allow lakes or other water impoundments to inundate formerly dry areas, or lower the ground surface below the local water table causing waterlogged soils and areas of ponded water. Earthquakes may also produce flooding due to damage of water storage or conveyance structures such as dams, pipelines, and canals.

A variety of magnitude scales are used to measure earthquake size (dePolo and Slemmons, 1990). The magnitude scale most commonly used today is the Richter scale (Richter, 1938, 1958; Bolt, 1988), which measures earthquake magnitude based on the amount of earthquake-induced ground shaking recorded on a seismograph. The Richter scale is logarithmic, having no upper or lower bounds, and each one-unit increase in the scale represents a ten-fold increase in the amplitude of ground displacement at a given location. The Richter scale's relation to earthquake energy release is also logarithmic so that each one-unit increase on the scale represents a 31.6-fold increase in energy release. Therefore, a Richter magnitude 6 earthquake is about 31.6 times more powerful than a magnitude 5 earthquake, and a magnitude 7 earthquake is about 1000 (31.6 multiplied by 31.6) times more powerful than a magnitude 5 event. Unless stated otherwise, all magnitudes reported here are Richter magnitudes (M). The human detection threshold for earthquakes is about M 2 and significant damage from earthquake ground shaking begins to occur at about M 5.5. In the Intermountain West, surface faulting typically accompanies earthquakes above about M 6.5.

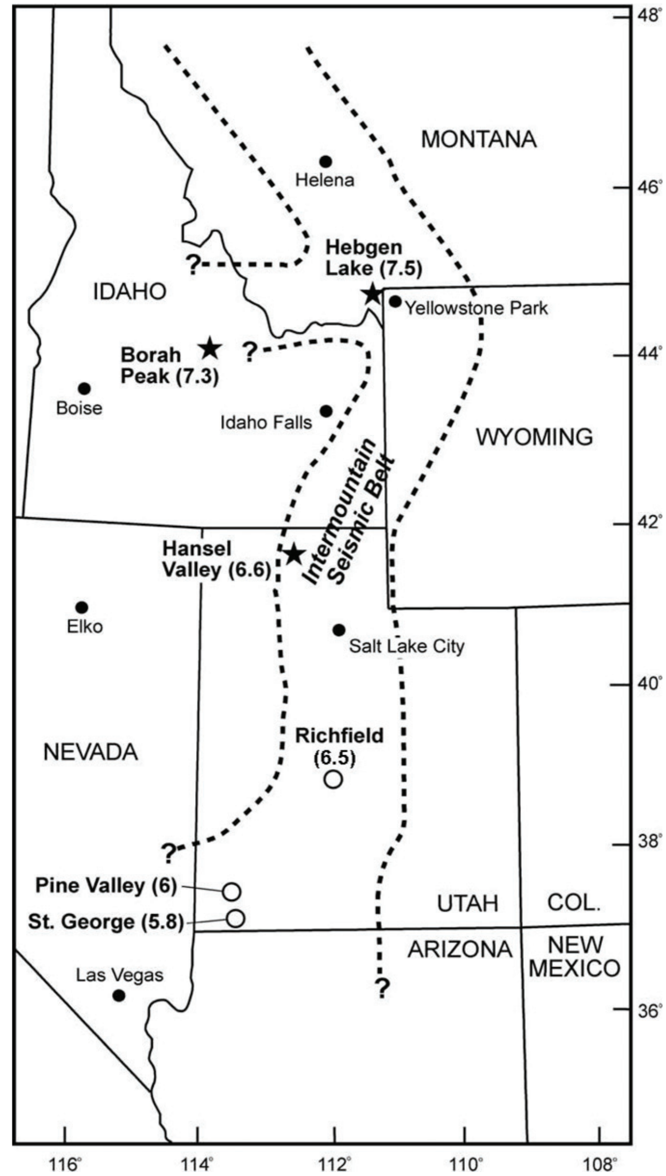

Figure 2.1. *The Intermountain Seismic Belt (ISB), earthquakes that produced surface-faulting in the ISB (stars), and significant historical, non-surface faulting earthquakes in Utah (open circles), with earthquake magnitude in parentheses (modified from Arabasz and others, 1992).*

EARTHQUAKES IN THE MAGNA QUADRANGLE

In Utah, most earthquakes are associated with the Intermountain Seismic Belt (ISB) (Smith and Sbar, 1974; Smith and Arabasz, 1991), an approximately 100-mile-wide (160 km), north-south trending zone of earthquake activity that extends from northern Montana to northwestern Arizona (figure 2.1). Since 1850, at least 35 independent earthquakes (aftershocks not included) of M 5.0 or greater have occurred within the ISB (Eldredge and Christenson, 2008). Included among those 35 earthquakes are Utah's two largest historical earthquakes: the 1901 Richfield earthquake, with an estimated M 6.5 (estimated from the size of the felt area because instrumental recordings were lacking), and the 1934 Hansel Valley M 6.6 earthquake, which produced Utah's only historical surface fault rupture (Eldredge and Christenson, 2008). In an average year, Utah experiences more than 700 earthquakes, but most are too small to be felt. Moderate magnitude (M 5.5–M 6.5) earthquakes occur every several years on average, the most recent being the M 5.8 St. George earthquake on September 2, 1992 (Christenson, 1995). Large magnitude earthquakes

(M 6.5–M 7.5) are much less frequent in Utah, but geologic evidence shows that most areas of the state within the ISB, including the Salt Lake Valley, have experienced large surface-faulting earthquakes in the recent geologic past. Several faults and fault zones pose a significant earthquake threat to structures in the Magna quadrangle, including the Wasatch fault zone, the West Valley fault zone, and the Harkers fault.

Numerous earthquakes greater than M 4 have occurred in northern Utah over the past century, including the 1962 Magna M 5.2 earthquake (University of Utah Seismograph Stations, 2010a; figure 2.2). This earthquake damaged buildings in several cities and towns (the damage was mostly minor), including Magna, located within one mile (1.6 km) to the southwest of the earthquake epicenter. Newspaper articles, photographs, and personal accounts of the 1962 Magna earthquake can be viewed on the University of Utah Seismograph Stations' (2010a) website. Eldredge and O'Brien (2001) present photographs and discuss geologic effects and building damage from this earthquake. Additional information on earthquake preparedness and safety can be found in the Utah Seismic Safety Commission (2008) handbook for earthquakes in Utah, *Putting Down Roots in Earthquake Country*, which can be accessed online at http://ussc.utah.gov/putting_down_roots.html.

EARTHQUAKE GROUND SHAKING

Description

Ground shaking is typically the most widespread, frequently occurring, and damaging earthquake hazard (Yeats and others, 1997). Ground shaking is caused by seismic waves, which originate at the source of the earthquake and radiate outward in all directions. The extent of property damage and loss of life due to ground shaking depends on factors such as (1) earthquake magnitude, (2) proximity of the earthquake to an affected location, (3) strength, duration, and frequency of earthquake ground motions, (4) nature of the geologic materials through which the ground motions travel, and (5) design of engineered structures (Costa and Baker, 1981; Reiter, 1990).

Under static conditions, a building need withstand only the vertical force of gravity to support its own weight. However, during an earthquake (dynamic conditions) a building is also subjected to horizontal forces. Horizontal ground motions are typically the most damaging type of earthquake ground shaking. Horizontal ground motions are expressed in decimal fractions of the acceleration due to gravity (1 *g*). As little as 0.1 *g* may cause damage to weak structures (buildings not specifically designed to resist earthquakes) (Richter, 1958). The horizontal ground motions experienced at any location depend on the geologic material and proximity to the earthquake source and may reach values greater than 1 *g*.

Large magnitude earthquakes typically cause more damage because they result in stronger ground shaking for longer periods of time. The strength of ground shaking generally decreases with increasing distance from the earthquake epicenter because the earthquake's energy scatters and dissipates as it travels through the earth. However, in certain cases earthquake ground motions can be amplified and shaking duration prolonged by local site conditions (Hays and King, 1982; Wong and others, 2002). The degree of amplification depends on factors such as soil thickness and the nature of geologic materials.

Methods and Sources of Data

Several different studies related to ground shaking have been completed for the Salt Lake Valley (including the Magna quadrangle). For this reason, we did not complete a ground-shaking-hazard map or analysis for the Magna quadrangle. Instead, we discuss the common methods used to analyze site-specific ground-shaking conditions and summarize the ground-shaking maps for the Salt Lake Valley that are pertinent to the Magna quadrangle.

International Code Council Seismic Design

The International Building Code (IBC) (International Code Council, 2009a) and the International Residential Code (IRC) (International Code Council, 2009b), which are adopted statewide, provide design and construction requirements for resisting earthquake motions (loads) based on a structure's seismic design category. To identify a structure's seismic design category, the IBC describes a procedure to determine the amount of ground-shaking amplification at a specific site. Determining an IBC seismic design category begins by defining a site class based on the types and engineering properties of soil and rock present in the upper 100 feet (30 m) beneath a proposed building site (IBC Section 1613.5.2, p. 341). The IBC defines Site Classes A through F (table 2.2). Site Classes A through E (hard rock to soft soil) may be defined on the basis of average shear-wave velocity, average standard penetration resistance (blow count), or average undrained shear strength (table 2.2). Additionally, soils may be classified as Site Class E or F depending upon other geotechnical characteristics that make them particularly vulnerable to earthquake ground shaking (table 2.2).

Next, maximum considered earthquake ground motions (maximum spectral response accelerations) on rock (Site Class B) are obtained from either IBC figures 1613.5(1) or 1613.5(2) (p. 348–351), or from the U.S. Geological Survey (USGS) National Seismic Hazard Maps at http://earthquake.usgs.gov/research/hazmaps. Different structures are affected by different ground-shaking frequencies, which when matching the natural frequency of vibration of a structure (a function of building height and construction type), may cause resonance resulting in severe damage or collapse. Therefore, the IBC and USGS provide maximum spectral response accelera-

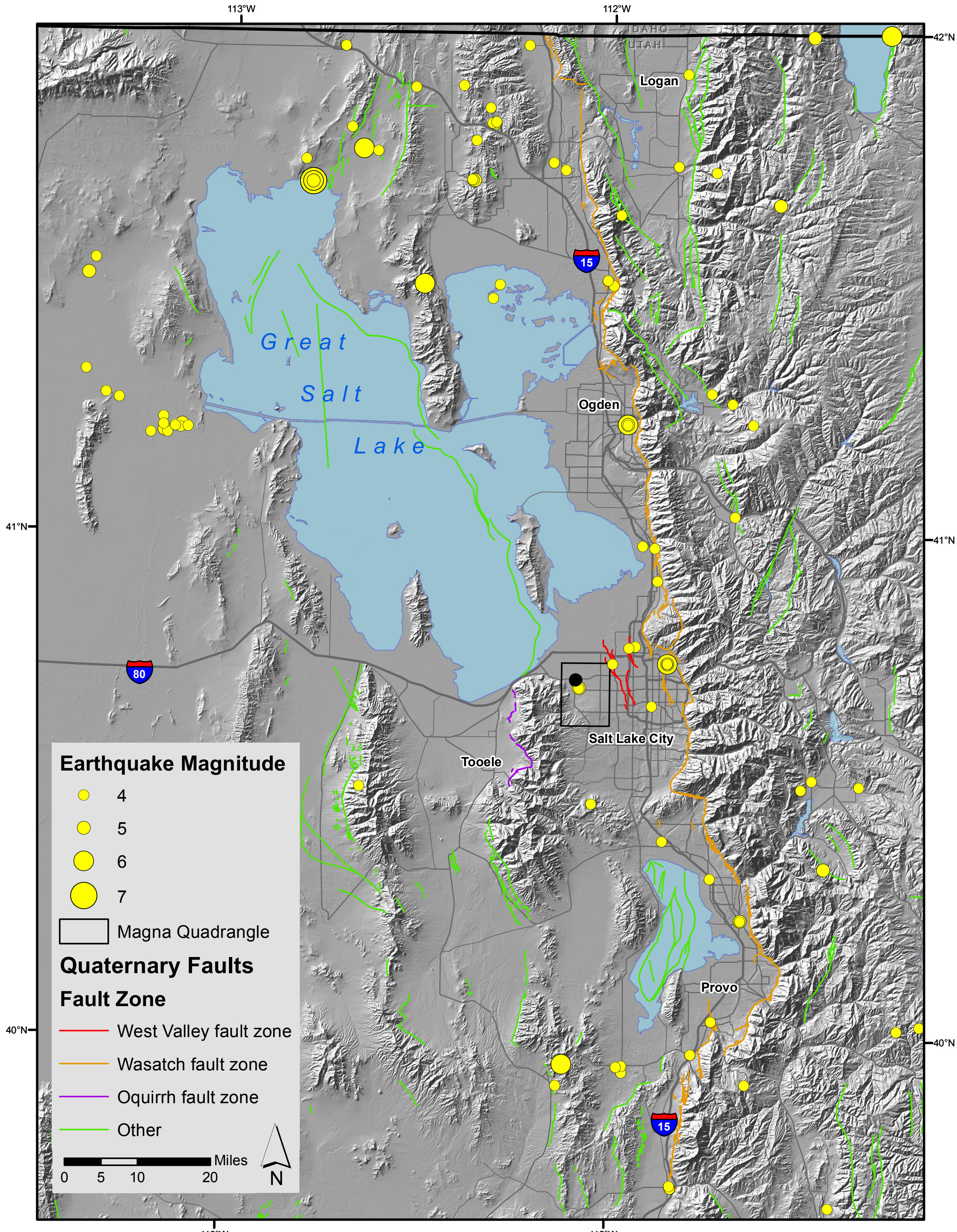

Figure 2.2. *Earthquake epicenter map of northern Utah from 1850 to 2009 (University of Utah Seismograph Stations, 2010b) and major Quaternary faults in the region (Black and others, 2003), including the Oquirrh fault zone (OFZ), West Valley fault zone (WVFZ), and Wasatch fault zone (WFZ). The area outlined in black shows the location of the Magna quadrangle. The black dot in the Magna quadrangle shows the location of the 1962 M 5.2 Magna earthquake.*

tions for two periods of ground motion (0.2 sec and 1.0 sec), which together are appropriate for a wide range of building types. The 0.2 sec maximum spectral response acceleration (S_s) is appropriate when evaluating the effect of short-period (high-frequency) ground motions, which typically affect short buildings (one to two stories). The 1.0 sec maximum spectral response acceleration (S_1) is appropriate when evaluating the effect of long-period (low-frequency) ground motions, which typically affect tall buildings (more than two stories).

Maximum spectral response accelerations are appropriate for a rock site (Site Class B), and must be adjusted for deamplification or amplification of earthquake ground motions due to other site-specific soil and rock conditions. Accelerations are adjusted using site coefficients. The IBC provides site coefficients (F_a and F_v) for each site class (except site class F) for both short period (F_a) and long period (F_v) ground motions. Site coefficients for the other site classes are calculated relative to the coefficient (1.0) for Site Class B. Site coefficients less than one indicate that ground motions will be less than those for Site Class B (deamplified). Site coefficients greater than one indicate that ground motions will be greater than those for Site Class B (amplified). The site coefficients for both short- and long-period ground motions for Site Class A (hard rock) are 0.8, indicating that ground shaking will be deamplified. The site coefficients for Site Classes C, D, and E (very dense soil or soft rock, stiff soil, and soft soil, respectively) range from 0.9 to 3.5, indicating that ground shaking may either be deamplified or amplified, depending upon the period and strength of ground motions; amplification generally increases as the period increases and soil or rock strength decreases. Because of the unique properties of soils in Site Class F, the IBC does not provide site coefficients for that site class. Instead, the IBC requires that site-specific geotechnical investigations and dynamic site-response analyses be performed to determine appropriate values.

Table 2.2. *IBC site-class definitions (modified from 2009 IBC table 1613.5.2).*

Site Class	Soil Profile Name	Average Properties in Top 100 Feet (30 m)		
		Shear-Wave Velocity – Vs ft/s (m/s)	**Standard Penetration Test – N (blows/ft)**	**Undrained Shear Strength – Su (psf)**
A	Hard rock	> 5,000 (> 1500)	n.a.	n.a.
B	Rock	2,500–5,000 (760–1500)	n.a.	n.a.
C	Very dense soil and soft rock	1,200–2,500 (360–760)	> 50	> 2,000
D	Stiff soil	600–1,200 (180–360)	15–50	1,000–2,000
E	Soft soil	< 600 (< 180)	< 15	< 1,000
		Any profile with more than 10 feet (3 m) of soil having the following characteristics: 1. Plasticity index > 20 2. Moisture content > 40% 3. Undrained shear strength < 500 psf		
F	---	Any profile containing soils having one or more of the following characteristics: 1. Soils vulnerable to potential failure or collapse under seismic loading such as liquefiable soils, quick and highly sensitive clays, collapsible weakly cemented soils 2. Peats and/or highly organic clays (> 10 feet [3 m] thick) 3. Very high plasticity clays (> 25 feet [8 m] thick with plasticity index> 75) 4. Very thick (> 120 feet [37 m]) soft/medium stiff clays		

Multiplying the site coefficients by the maximum spectral response accelerations produces the adjusted maximum considered earthquake spectral response accelerations (S_{MS} and S_{M1}) that account for ground-motion amplification or deamplification due to site-specific soil or rock conditions. The adjusted maximum considered earthquake spectral response accelerations are then multiplied by 2/3 to arrive at design spectral response accelerations (S_{DS} and S_{D1}). The seismic design category for the structure is then determined by comparing the design spectral response acceleration with the proposed structure's IBC Occupancy Category (IBC table 1604.5; p. 307) using IBC tables 1613.5.6(1) and 1613.5.6(2) (p. 343). Buildings and structures are assigned the more severe seismic design category, regardless of the fundamental vibration period of the structure. The resulting seismic-design category determines the applicable seismic-design requirements for the structure.

This procedure is automated using the USGS Java Ground Motion Parameter Calculator available at http://earthquake.usgs.gov/research/hazmaps/design/ (check the USGS website for the most recent version of the calculator).

U.S. Geological Survey National Seismic Hazard Maps

The USGS National Seismic Hazard Maps (2008) include generalized probabilistic ground-shaking maps of Utah for IBC Site Class B. The maps display likely earthquake ground motions (including 0.2 sec and 1.0 sec spectral accelerations) for various probabilities of occurrence and are used in selected public codes and ordinances, including the IBC. However, the maps have limited resolution and do not consider ground-shaking effects for other IBC site classes or incorporate sedimentary basin and soil models into their hazard studies.

Earthquake Site Conditions

A study by McDonald and Ashland (2008) used shear wave velocity profile data to characterize site conditions, including the delineation of IBC site class units, along the Wasatch Front. The study can be used to approximate soil behavior at a site during a moderate- to large-magnitude earthquake affecting the Wasatch Front area, although site-specific data are required for accurate estimates.

Earthquake Scenario and Probabilistic Ground-Shaking Maps

Wong and others (2002) completed probabilistic ground-shaking maps for the Salt Lake Valley, including the Magna quadrangle. Their study incorporates the site-response effects of unconsolidated sediments that underlie much of Salt Lake Valley and maps the surficial ground-shaking hazard for several earthquake scenarios. Included are peak horizontal ground acceleration and 0.2 sec and 1.0 sec spectral acceleration maps for the following scenarios: M 7.0 earthquake, 10% probability of exceedance in 50 years, and 2% probability of exceedance in 50 years. Wong and his colleagues are currently in the process of revising these maps by incorporating new data.

Community Velocity Model

The Wasatch Front Community Velocity Model (CVM) (Magistrale and others, 2009) is an important component in the development of future ground-shaking maps. The CVM is a three-dimensional model of the subsurface developed to aid in simulating ground motions expected during an earthquake in the highly urbanized part of the Wasatch Front. The CVM provides researchers with a unified subsurface velocity model that can be used to simulate effects including strong motion, seismicity location, and tomographic velocity by incorporating elements such as soil classes, basin geometry, basin-sediment interfaces, crustal tomography, and the Moho. The latest version of the CVM is available for download on the UGS website at http://geology.utah.gov/ghp/consultants/geophysical_data/index.htm.

Scenario Earthquake Models

One method of predicting the ground-shaking effects in a specific area is to model ground motions for a particular earthquake magnitude. Solomon and others (2004) mapped earthquake-related hazards, including ground shaking, for a theoretical M 7 earthquake on the Salt Lake segment of the Wasatch fault with a 29-mile-long (47 km) and 12-mile-wide (19 km) rupture plane, dipping 55 degrees to the west. This study can be used to estimate the consequences of the M 7-scenario earthquake, expands upon the study completed by Wong and others (2002), and contains scenario (M 7) and probabilistic (0.2-sec and 1.0-sec spectral accelerations) ground-shaking maps that include the Magna quadrangle.

Hazard Reduction

The hazard associated with earthquake ground shaking can be both widespread and costly in terms of property damage, injury, and death depending on location and earthquake magnitude. Ground shaking cannot be avoided, but meeting requirements for building-code-based earthquake-resistant design and construction requirements in new construction and retrofitting existing structures (as outlined in the IBC and IRC) can reduce loss of life and damage to structures. Seismic provisions of the IBC and IRC are intended to minimize injury and loss of life by ensuring the structural integrity of a building, but do not ensure that a structure or its contents will not be damaged during an earthquake. Additionally, because a large portion of injuries during an earthquake are caused by falling objects resulting from ground shaking, the UGS recommends that heavy objects that may fall or topple over during an earthquake be secured. Fire caused by damage to gas pipelines during an earthquake is also a significant hazard related to ground shaking. This hazard may be reduced by securing gas water heaters to minimize the potential for breaking supply lines, and by keeping tools on hand to shut off gas valves if needed (Utah Seismic Safety Commission, 2008).

The UGS recommends that site-specific characterization of ground-shaking probabilities be completed as part of a site-specific geotechnical/geologic-hazard investigation prior to development at all locations in the quadrangle. Site-specific geotechnical/geologic-hazard investigations are intended to ensure that buildings will be designed and constructed to resist the effects of earthquake ground motions in accordance with the IBC occupancy categories. These effects may be particularly severe in areas subject to amplified ground motions. Because of uncertainties associated with the data used in regional studies and the critical role of site-class designations in building design, the IBC site class should be confirmed in the field during site-specific geotechnical/geologic-hazard investigations prior to construction, for all projects as outlined in the IBC or IRC.

LIQUEFACTION SUSCEPTIBILITY

Description

Liquefaction and liquefaction-induced ground failures are major causes of earthquake damage (Keller and Blodgett, 2006). Upon liquefaction, a soil loses its strength and ability to support the weight of overlying structures or sediments. Liquefaction typically occurs within 50 feet (15 m) of the ground surface (Seed, 1979), and may occur at greater depths on slopes near a free face or where foundations are deeper, but the likelihood of liquefaction occurring in most deposits is very low when groundwater is deeper than about 30 feet (10 m) (Youd and Perkins, 1978). In the absence of a free face or deep foundations, the California Geological Survey considers groundwater deeper than 50 feet (15 m) an obvious indicator of a low potential for liquefaction and comprehensive field investigation is commonly unnecessary, although the effects of perched groundwater and seasonal variations in the water table must be evaluated (Martin and Lew, 1999; California Geological Survey, 2008).

Liquefaction occurs when water-saturated, loose soil is subjected to strong ground shaking (Seed, 1979; Martin and Lew, 1999). Loose soils are typically sandy, with little clay, and have grains that do not readily adhere together, although some silty and gravelly soils are also susceptible to liquefaction. In general, an earthquake of M 5 or greater is necessary to induce liquefaction. Larger earthquakes are more likely to cause liquefaction, and may result in liquefaction at greater distances from the earthquake epicenter.

Liquefaction and liquefaction-induced ground failure can cause major damage to structures and infrastructure. Foundations may crack; buildings may tip; buoyant buried structures, such as septic tanks and storage tanks, may rise; and landslides may occur, even on gentle slopes. Structures that are particularly sensitive to liquefaction-induced ground failure include buildings with shallow foundations, railway lines, highways and bridges, buried structures, dams, canals, retaining walls, utility poles, and towers.

Four types of ground failure commonly result from liquefaction: (1) loss of bearing capacity, (2) ground oscillation and subsidence, (3) lateral spreading, and (4) flow failures (Youd, 1978; Youd, 1984; Tinsley and others, 1985) (figure 2.3). The expected mode of ground failure at a given site largely depends upon the ground-surface slope. Where the slope is less than 0.5 percent, the expected mode of ground failure also depends upon the depth to the liquefiable layer. On such slopes, loss of bearing capacity is likely if the liquefiable layer is relatively shallow, and ground oscillation and subsidence are likely if the liquefiable layer is relatively deep.

Loss of bearing capacity and resulting deformation of soil beneath a structure are the principal effects of liquefaction in areas where slopes are less than 0.5 percent. Loss of bearing capacity in foundation soils causes structures to settle or tilt. Differential settlement is commonly accompanied by cracking of foundations and damage to structures. Buried structures, such as gasoline-storage or septic tanks, may become buoyant and float upward in liquefied soils.

Ground oscillation takes place on slopes less than 0.5 percent when liquefaction occurs in soil layers at depth while overlying soil layers do not liquefy. Under these conditions, liquefaction at depth commonly causes overlying soil blocks to detach and jostle back and forth on the liquefied layer. Damage to structures and buried facilities is caused by subsidence of the blocks, opening and closing of fissures between and within the blocks, and formation of sand blows as liquefied sand is ejected through the fissures from the underlying pressurized liquefied layer.

Ground failure by lateral spreading may occur where the ground surface slopes from 0.5 to 5 percent, particularly near “free faces” such as stream banks or cut slopes. Lateral spreads are characterized by surficial soil blocks that are displaced laterally downslope as a result of liquefaction in a subsurface layer. Lateral spreading can cause significant damage to structures and may be particularly destructive to pipelines, utilities, bridge piers, and structures with shallow foundations.

Flow failures may occur where the ground surface slopes more than about 5 percent. Flow failures are composed chiefly of liquefied soil or blocks of intact material riding on a liquefied layer. Flow failures can cause soil masses to be displaced several miles and are the most catastrophic mode of

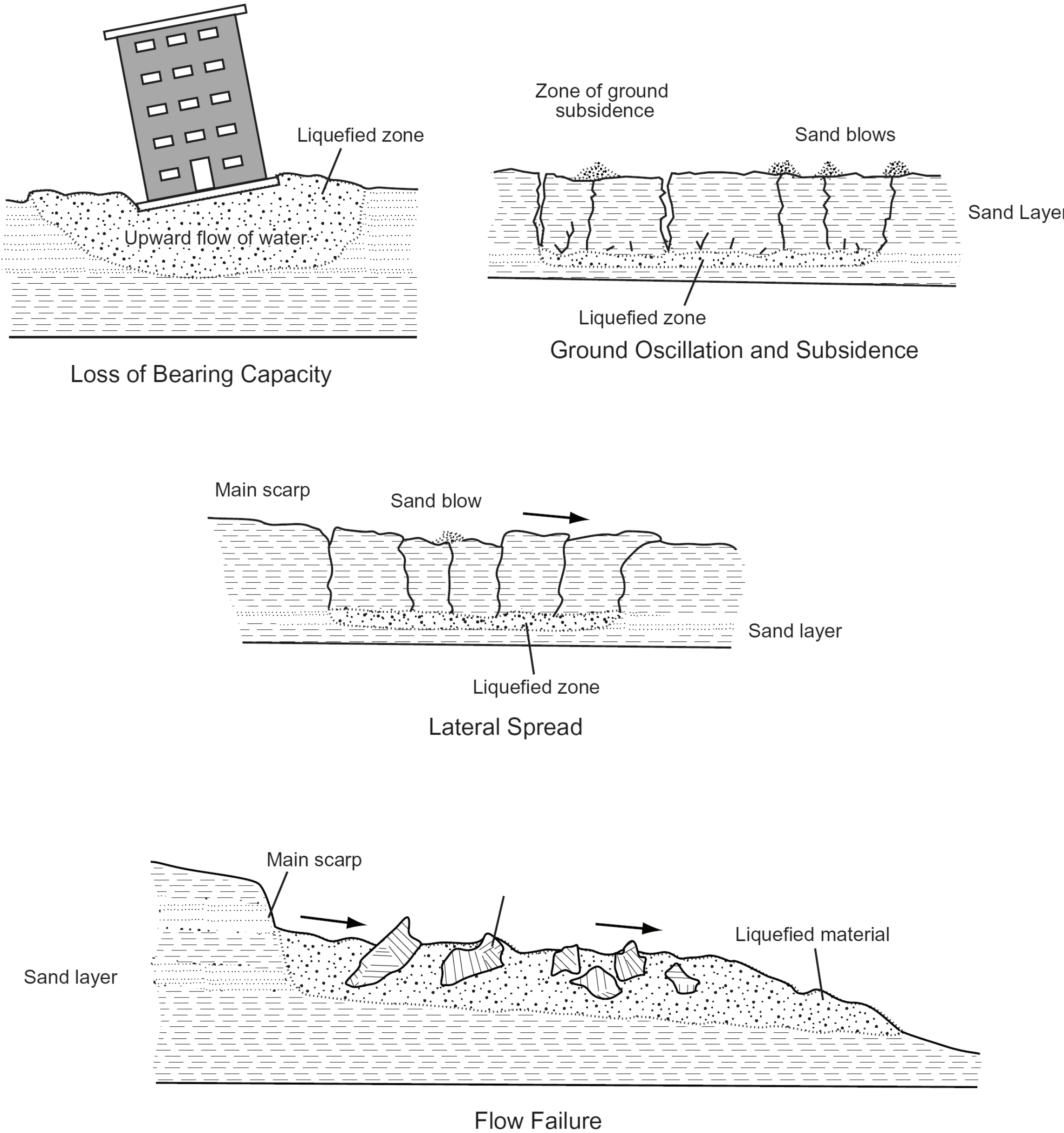

Figure 2.3. *Four principal types of liquefaction-induced ground failure. Arrows indicate direction of ground movement (modified from Youd, 1984).*

liquefaction-induced ground failure.

Recent examples of liquefaction in Utah resulted from the 2010 M 4.9 earthquake near Randolph (Chris DuRoss, UGS, verbal communication, 2010) and the 1992 M 5.8 earthquake near St. George (Black and others, 1995). Liquefaction from the Randolph earthquake occurred in Bear River alluvium. The Randolph earthquake is one of the smallest earthquakes recorded with modern instrumentation to produce liquefaction. Liquefaction from the St. George earthquake occurred in Virgin River alluvium, where lateral spreads, sand blows, and caved stream banks were observed but no damage was documented. A site on the Bear River, 4.5 miles (7.2 km) west of Richmond, experienced liquefaction during the 1962 M 5.7 Richmond earthquake in Cache Valley (Hill, 1979). A large number of sand blows formed in Bear River alluvium but resulted in no damage. A 0.6 mile (1 km) stretch of the Bear River also experienced liquefaction (mostly sand blows) during the 2010 M 4.9 Randolph earthquake, but the extent of liquefaction was limited and only occurred near the epicenter (approximately 0.6 mile [1 km] from where the liquefaction occurred).

In general, Quaternary lacustrine sediments in the Magna quadrangle are susceptible to liquefaction in areas of shallow groundwater. High and moderate liquefaction hazard areas are located in the northern and eastern portion of the quadrangle; however, the geology of the Salt Lake Valley, including the northwest portion where the Magna quadrangle is located, is highly variable. Inter-bedded clay, silt, sand, and gravel deposited during the Bonneville Lake cycle (Solomon and others, 2007) give rise to a complex geologic environment in which liquefaction hazards can differ at varying depths and locations.

Methods and Sources of Data

We evaluated liquefaction susceptibility using four main sources of data to determine the types of geologic materials and groundwater depths: (1) recent geologic mapping (Solomon and others, 2007), (2) a geotechnical database compiled for this report, (3) the U.S. Natural Resources Conservation Service (NRCS) *Soil Survey Geographic (SSURGO) Database for Salt Lake Area, Salt Lake County, Utah* (NRCS, 2006), and (4) shallow groundwater mapping completed for this report (see chapter 8). We assigned a liquefaction classification of high, moderate, low, very low, or no susceptibility based on geologic and groundwater conditions (plate 1).

Anderson and others (1994) emphasized that perched groundwater is equal to true groundwater with respect to soil liquefaction, stating that saturated granular material is the chief concern; the source of the saturation is immaterial. We mapped three shallow groundwater-potential categories: (1) areas of known shallow groundwater (< 10 ft [3 m]), (2) poorly drained geologic units and soils likely to cause shallow groundwater and perched groundwater conditions, and (3) freely draining soils, where shallow groundwater is unlikely. Our liquefaction-susceptibility map differs from the study by Anderson and others (1994) due to the incorporation of recent geologic and shallow groundwater mapping. For descriptions of the groundwater-potential categories on the shallow groundwater-potential map, refer to chapter 8 of this report.

We used geologic mapping, NRCS soil data, and soil boring logs from our geotechnical database to delineate unconsolidated geologic deposits typically associated with liquefaction. We evaluated each geologic map unit based on dominant grain-size distribution (fine to coarse grained), sorting (poorly to well sorted), and cementation (none to strong). We then integrated the soil/geologic deposit data with the groundwater data. Where depth to groundwater is likely 50 feet (15 m) or less, we classified the liquefaction susceptibility of the corresponding geologic unit as high, moderate, low, or very low, based on textural characteristics and cementation. Geologic units that consist of well sorted sands, silty sands, and gravels where depth to groundwater is less than or equal to 50 feet (15 m) below the ground surface are mapped as high. Geologic units that consist of moderately to poorly sorted sands and gravels where depth to groundwater is less than or equal to 50 feet (15 m) below the ground surface are mapped as moderate. Geologic units that consist of moderately to poorly sorted sands and gravels, where depth to groundwater is greater than or equal to 50 feet (15 m) below the ground surface are mapped as low. Geologic units that consist of poorly sorted sands and gravels where depth to groundwater is greater than 50 feet (15 m) are mapped as very low. Areas of fine-grained material and perched or seasonally high groundwater may also increase the liquefaction hazard within the mapped low and very low hazard areas.

Areas of no liquefaction susceptibility include Tertiary, Permian, and Pennsylvanian bedrock outcrops. Consolidated bedrock units are considered to have no liquefaction hazard; however, small areas of liquefaction hazard too small to show at the scale of this study may exist locally within areas of the map that have no hazard designation.

Using This Map

Mapped areas of liquefaction susceptibility in the Magna quadrangle are shown on plate 1. The map does not integrate earthquake ground motions with soil characteristics and depth to groundwater, which is required to determine relative liquefaction potential (potential is equal to susceptibility plus opportunity) in susceptible soils. Probabilistic liquefaction potential and liquefaction-induced ground-failure mapping for the urban Wasatch Front, beyond the scope of this map, is ongoing at the University of Utah in collaboration with the Utah Liquefaction Advisory Group (ULAG) and other universities (Bartlett and others, 2005; 2006). This map also does not differentiate ground-failure types or amounts, which are needed to fully assess the hazard and evaluate possible mitigation techniques.

The liquefaction-susceptibility map is intended for general planning purposes to indicate where liquefaction susceptibility may be present and to assist in designing liquefaction-hazard investigations. Requirements for liquefaction investigations are given in the International Building Code (IBC) (International Code Council, 2009a) and are implied in the International Residential Code (IRC) (International Code Council, 2009b), which applies to the design and construction of one- and two-family dwellings and townhouses. IBC Section 1803.5.11 (p. 388) requires a liquefaction evaluation if a structure is in Seismic Design Category C, D, E, or F, and IBC Section 1803.5.12 (p. 389) requires a liquefaction evaluation and an assessment of potential consequences of any liquefaction if the structure is in Seismic Design Categories D, E, or F. Although the IRC does not specifically mention liquefaction, IRC Section R401.4 (p. 71) leaves the need for soil tests up to the local building official in areas likely to have expansive, compressive, shifting, or other questionable soil characteristics, such as liquefiable soils.

IBC seismic design categories are described in IBC section 1613.5.6. Seismic design categories are determined on a site- or project-specific basis, and vary throughout the Magna quadrangle depending on IBC Site Class, maximum considered earthquake ground motions, and the IBC Occupancy Category of the proposed structure. Occupancy Categories are based on the nature of the structure's use and occupancy and are described in IBC Section 1604.5 (p. 306) and table 1604.5 (p. 307). The IBC specifies four Occupancy Categories (I, II, III, and IV). Occupancy Category I includes buildings and other structures, such as temporary or storage facilities, that represent a low hazard to human life in the event of a failure. Occupancy Category II includes single and multi-family residences, and those buildings and other structures not listed in Occupancy Categories I, III, and IV, including single family homes and townhomes. Occupancy Category III includes buildings and other structures, such as schools, that represent a substantial hazard to human life in the event of failure. Occupancy Category IV includes buildings and other structures designated as essential facilities, such as critical utility facilities and hospitals.

The Salt Lake County Geologic Hazards Ordinance (Salt Lake County, 2010) outlines County requirements for liquefaction investigations prior to development. Table 2.3 shows County requirements based on intended land use and incorporates the corresponding IBC occupancy category. The requirements outlined by Salt Lake County are the minimum requirements for development approval. Martin and Lew (1999) provide guidelines for conducting both reconnaissance (screening) and detailed (quantitative) liquefaction evaluations. In conjunction with the Salt Lake County requirements, we recommend at a minimum:

- reconnaissance investigations for all Occupancy Category II and III structures be conducted in all hazard areas,
- a detailed investigation if the liquefaction hazard is determined to be moderate or greater, and
- a reconnaissance evaluation only for Occupancy Category I structures in moderate to high liquefaction-hazard areas.

No investigation is required for Occupancy Category I buildings in low, very low, or no susceptibility areas.

Map Limitations

The liquefaction-susceptibility map (plate 1) is based on limited geological, geotechnical, and hydrological data. The quality of the map depends on the quality of these data, which vary throughout the study area. The mapped boundaries be-

Table 2.3. *Liquefaction investigations and reports required prior to development approval. After Salt Lake County Geologic Hazard Ordinance table 19.75.050 (Salt Lake County, 2010).*

Land Use and IBC Occupancy Correlation		Liquefaction Potential	
Land Use (Type or Facility)	IBC Occupancy Category	High and Moderate	Low and Very Low
Critical and essential facilities as defined in Section 19.75.020 of the Salt Lake County Geologic Hazards Ordinance	IV	Yes	Yes
Industrial and commercial buildings (1 story and < 5,000 sq. ft.)	II	No*	No
Industrial and commercial buildings (> 5,000 sq. ft.)	III	Yes	No
Residential-single family lots/single family homes	II	No*	No
Residential subdivisions (> 9 lots), and residential multi-family dwellings (4 or more units per acre)	II	Yes	No
Residential subdivisions (< 9 lots), and residential multi-family dwellings (< 4 units per acre)	II	No*	No

*Although a site-specific investigation is not required, the owner is required to file a disclosure notice prior to land-use approval.

tween liquefaction-susceptibility categories are approximate and subject to change with additional information. The liquefaction susceptibility at any particular site may be different than shown because of geologic and hydrologic variations within a map unit, gradational and approximate map unit boundaries, and the generalized map scale. Small, localized areas of higher or lower liquefaction susceptibility may exist anywhere within the study area, but their identification is precluded due to limitations of either data or map scale. Seasonal and long-term fluctuations in groundwater levels can alter liquefaction susceptibility at any given site. The map is not intended for use at scales other than 1:24,000, and is designed for use in general planning to indicate the need for site-specific geotechnical/geologic-hazard investigations. Site-specific geotechnical/geologic-hazard investigations are required to produce more detailed information.

Hazard Reduction

Although potentially costly when not recognized and properly accommodated in project design, problems associated with liquefaction are rarely life threatening. As with most geologic hazards, early recognition and avoidance are the most effective way to mitigate this hazard. However, avoidance may not always be a viable or cost-effective hazard-reduction option, and other techniques are available to reduce liquefaction hazards (National Research Council, 1985).

Liquefaction damage may be reduced either by improving site conditions to lower liquefaction hazard (for example, compacting or replacing soil, or installing drains or pumps to lower the water table) or by designing structures to withstand liquefaction effects (using deep foundations or structural reinforcement). Existing structures threatened by liquefaction may be retrofitted to reduce the potential for damage. The cost of reducing liquefaction hazards for existing structures may be high relative to their value. Therefore, the UGS considers it prudent, although not essential, to reduce liquefaction hazards for existing structures; however, in areas where significant ground deformation (lateral spreading) is anticipated and the structures fall into IBC Occupancy Categories III or IV, we recommend retrofitting. At a minimum, we recommend disclosure of study results if studies confirm a moderate to high liquefaction potential. Disclosure allows prospective buyers to make an informed decision on the amount of risk they are willing to accept.

SURFACE FAULT RUPTURE

Description

Among the potential damaging effects of large earthquakes is surface fault rupture, which occurs when earthquake movement at depth propagates along the fault to the ground surface. The resulting displacement of the ground surface may also produce ground cracking and warping, and may result in more than one fault scarp. Depending on the magnitude of the earthquake, fault scarps can range from a few inches to several feet high and extend for many miles along the fault trace. Local ground tilting and graben formation by secondary faulting may accompany surface fault rupture, resulting in a zone of deformation along the fault trace that can be tens to hundreds of feet wide. Surface fault rupture, while of limited aerial extent when compared to other earthquake-related hazards (such as ground shaking), can have serious consequences for structures or other facilities that lie along or cross the rupture path.

The West Valley fault zone poses a surface-fault-rupture hazard in the Magna quadrangle. The West Valley fault zone includes the Granger and Taylorsville faults in addition to many smaller faults. The Granger and Taylorsville faults are subparallel and trend roughly north-northwest, with the Granger fault to the west and the Taylorsville fault to the east. The Granger fault is a high-angle, down-to-the-east, normal fault that extends into the northeastern corner of the quadrangle (plate 2). Paleoseismic investigations on the Granger fault show that the fault has produced surface-fault-rupturing earthquakes in the past 10,000 years (Keaton and others, 1993). Radiocarbon dating of charcoal collected from fault-related sediments on the Granger fault indicates the most recent surface-faulting earthquake was 1300–1700 thousand years ago (Black and others, 2003). The UGS recommends investigations for surface fault-rupture for all structures intended for human occupancy and for all critical facilities located within the designated special-study zones along the Granger fault.

Other faults that pose a potential hazard of surface fault rupture in the Magna quadrangle are the Harkers fault, in the southwestern corner, and a currently unnamed fault mapped to the north of the Harkers fault (Solomon and others, 2007). Both the Harkers fault and the unnamed fault are north-northeast trending normal faults cutting older Quaternary alluvial-fan deposits; however, little else is known about these faults. Due to the age of the displaced deposits (upper to middle Pleistocene to upper Miocene), the potential for surface fault rupture is low; however, the hazard from surface fault rupture should be investigated for all critical facilities within the special-study zones for these faults.

Methods and Sources of Data

We evaluated surface-fault-rupture hazard using recent geologic mapping (Solomon and others, 2007) and the *Quaternary Fault and Fold Database and Map of Utah* (Black and others, 2003) to determine the type (well defined, concealed, or approximately located) and location of faults on the Magna quadrangle. To establish special-study zones for surface-fault-rupture hazard we followed *Guidelines for Evaluating Surface-Fault-Rupture Hazards in Utah* (Christenson and others, 2003)

Fault Activity Levels

In California, the Alquist-Priolo Earthquake Fault Zoning Act (Bryant and Hart, 2007), which regulates development along known active faults, defines an "active fault" as one that has had "surface displacement within Holocene time (about the past 11,000 years)." Because California has a well-recognized earthquake hazard and was the first state to implement regulations designed to reduce those hazards, the California "Holocene" standard is used in many regulations in other parts of the country, even in areas where the Holocene is not the best time frame against which to measure surface-faulting recurrence. DePolo and Slemmons (1998) argue that in the Basin and Range Province, a time period longer than the Holocene is more appropriate for defining active faults because most faults in the province have surface-faulting recurrence intervals (average repeat times) that approach or exceed 10,000 years. They advocate a latest Pleistocene age criteria, specifically 130,000 years, to define active faults in the Basin and Range Province. They base their recommendation on the observation that six to eight (> 50%) of the 11 historical surface-faulting earthquakes in the Basin and Range Province occurred on faults that lacked evidence of Holocene activity, but which did have evidence of late Pleistocene activity.

Because of the difficulties in using a single "active" fault definition, Christenson and others (2003) recommend adopting the fault activity classes defined by the Western States Seismic Policy Council (WSSPC) for the Basin and Range Province (WSSPC Policy Recommendation 11-2, 2011; first adopted in 1997 as WSSPC Policy Recommendation 97-1, and revised and readopted in 2002, 2005, 2008, and 2011 [WSSPC, 2011]):

- Holocene fault – a fault that has moved within the past 11,700 calibrated years before present (B.P.).
- Late Quaternary fault – a fault that has moved within the past 130,000 years.
- Quaternary fault – a fault that has moved within the past 2,600,000 years.

The faults on the surface-fault-rupture hazard map (plate 2) are color-coded to indicate what is presently known about their activity level. Each color-code category includes recommendations for surface-fault-rupture special studies based on the fault activity class and the type of structure proposed (table 2.4). These recommendations are updated from those in the UGS *Guidelines for Evaluating Surface-Fault-Rupture Hazards in Utah* (Christenson and others, 2003) based on WSSPC Policy Recommendation 11-2; however, the Christenson and others (2003) provide recommendations for investigating and reporting surface-fault-rupture hazards, and procedures for establishing safe setback distances from active faults.

Special-Study Areas

Based upon recent geologic mapping (Solomon and others, 2007), we categorized Quaternary faults in the Magna quadrangle as "Well Defined" or "Concealed or Approximately Located." We then established special-study areas for surface-fault-rupture hazard (Robison, 1993; Christenson and others, 2003) for each fault category.

We considered a fault well defined if its trace is clearly detectable by a trained geologist as a physical feature at the ground surface (Bryant and Hart, 2007). We classified normal faults (where the hanging wall appears to have moved downward

Table 2.4. *Fault color codes for the map of surface-fault-rupture hazards (plate 2), and recommended special-study requirements for activity levels.*

Color	Activity Level	Special-Study Requirements
Red	Holocene or suspected Holocene	All structures designed for human occupancy[1], essential facilities[2], and all critical facilities[3]
Black	Unknown, recommend treating as Holocene until proven otherwise	All structures designed for human occupancy[1], essential facilities[2], and all critical facilities[3]

[1]Structure designed for human occupancy means any residential dwelling or any other structure used or intended for supporting or sheltering any use or occupancy, which is expected to have an occupancy rate of at least 2000 person-hours per year, but does not include an accessory building.

[2]Essential facility means buildings and other structures intended to remain operational in the event of an adverse geologic event, including but not limited to public utility facilities; dams, reservoirs, and other water storage facilities; jails and other detention facilities; emergency vehicle fueling and storage facilities; designated emergency shelters; emergency preparedness, response, and communication facilities; aviation control towers, air traffic centers, and emergency aircraft hangers.

[3]Critical facility means Occupancy Category III and IV structures as defined in the International Building Code (IBC, table 1604.5, p. 307; International Code Council, 2009a), and includes schools, hospitals and other health-care facilities; fire, rescue, and police stations; high occupancy buildings; water storage and treatment facilities, and facilities containing hazardous materials.

relative to the footwall [figure 2.4]) as "well defined" if the UGS 1:24,000-scale mapping shows them as solid lines, indicating that they are recognizable as faults at the ground surface. The special-study areas established for well-defined faults extend for 500 feet (150 m) on the downthrown side of the fault and 250 feet (75 m) on the upthrown side of the fault.

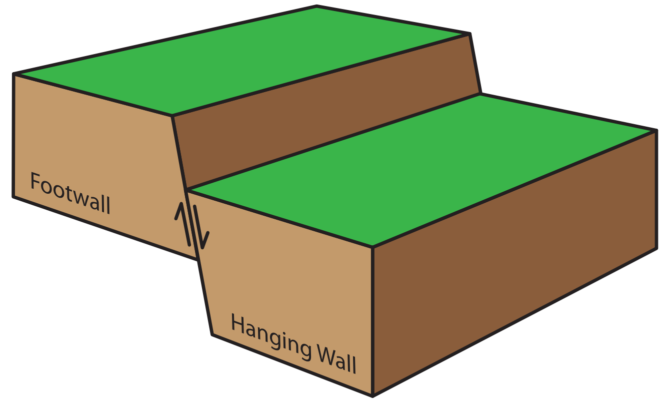

Figure 2.4. *Diagram of a normal fault showing the hanging wall and footwall.*

Solomon and others (2007) mapped two normal faults in the study area as concealed (dotted lines) or approximately located (dashed lines) because the traces of those faults are not evident at the ground surface. The reasons for the lack of clear surface evidence for these faults are varied, but are chiefly related to one of the following causes: (1) long earthquake recurrence intervals combined with a long elapsed time since the most recent surface-faulting earthquake allow evidence for the faults to be obscured by subsequent erosion and deposition, (2) rapid deposition in some areas quickly obscures faults, even those with comparatively short recurrence intervals, (3) the faults generate earthquakes that produce relatively small scarps (< 3 feet [1 m]) that are quickly obscured, and (4) faulting occurs at or above the bedrock/alluvium contact in relatively steep terrain and is difficult to identify.

Although not evident at the surface, these faults still may represent a significant surface-fault-rupture hazard and should be evaluated prior to development in areas where they may rupture the ground surface. Because their location is uncertain, the special-study areas around these faults are broader, extending 1000 feet (300 m) on each side of the suspected trace of the faults.

Using This Map

The surface-fault-rupture hazard map (plate 2) shows potentially active faults on the Magna quadrangle along which surface faulting may occur. A special-study area is shown around each fault, within which the UGS recommends a site-specific investigation of surface-fault-rupture hazard be performed prior to development. Site-specific geotechnical/geologic-hazard investigations can resolve uncertainties inherent in the generalized map scale and help ensure safety by identifying the need for fault setbacks. The *Guidelines for Evaluating Surface-Fault-Rupture Hazards in Utah* (Christenson and others, 2003) includes a detailed rationale for investigating and reporting surface-fault-rupture hazards, and procedures for establishing safe setback distances from active faults. City and county officials, planners, and consultants should refer to the guidelines for the details of conducting and reviewing investigations of surface-fault-rupture hazards. For well-defined faults, we recommend that investigations be performed in accordance with the UGS guidelines (Christenson and others, 2003). Because concealed and approximately located faults lack a clearly identifiable surface trace, they are not amenable to trenching, which is the standard hazard evaluation technique used to study well-defined faults (McCalpin, 2009). Where development is proposed in a special-study area for a concealed or approximately located fault, we recommend that at a minimum the following tasks be performed to better define the surface-fault-rupture hazard in those areas.

1. Review of published and unpublished maps, literature, and records concerning geologic units, faults, surface and groundwater, previous subsurface investigations, and other relevant factors.
2. Stereoscopic interpretation of aerial photographs to detect any subtle fault-related features expressed in the site topography, vegetation, or soil contrasts, and any lineaments of possible fault origin.
3. Field evaluation of the proposed site and surrounding area to observe surface evidence for faulting; map geologic units as necessary to define critical geologic relations; evaluate geomorphic features such as springs or seeps (aligned or not), sand blows or lateral spreads, or other evidence of earthquake-induced features; and excavate test pits to evaluate the age of deposits onsite to constrain the time of most recent surface faulting.

If the results of these investigations reveal evidence of possible surface-faulting related features, those features should be trenched in accordance with the UGS guidelines (Christenson and others, 2003). In addition, we recommend that construction excavations and cuts be carefully examined for evidence of faulting as development proceeds.

Map Limitations

Plate 2 is based on recent 1:24,000-scale geologic mapping (Solomon and others, 2007). It is our opinion that the inventory of potentially active faults obtained from that mapping and shown on the plate 2 is complete at that scale. However, smaller faults may not have been detected during mapping or may be concealed beneath young geologic deposits. Additionally, concealed and approximately located faults by definition lack a clearly identifiable surface trace; therefore, their locations are approximate. Site-specific fault-trenching investigations should be preceded by a careful field evaluation of the site to identify the surface trace of the fault, other faults, and fault-related features not evident at 1:24,000-scale.

Hazard Reduction

Because surface faulting is typically confined to relatively narrow zones along the surface trace of a fault, early recognition and avoidance are the most effective strategies for mitigating this hazard. Carefully locating all potentially active fault traces on a site, assessing their level of activity and amount of displacement, and establishing an appropriate setback distance from the fault remain the most reliable procedures for mitigating damage and injury due to surface faulting. We recommend that facilities be set back from the fault trace and any associated zone of deformation in accordance with the UGS guidelines (Christenson and others, 2003). In Utah, earthquake-resistant design requirements are specified in the seismic provisions of the IBC (International Code Council, 2009a) and IRC (International Code Council, 2009b), which are adopted statewide.

REGIONAL SUBSIDENCE

Regional subsidence, also referred to as tectonic subsidence, is the warping, lowering, and tilting of a valley floor that accompanies surface-faulting earthquakes on normal faults, such as those bounding the Magna quadrangle. Geologic evidence indicates tectonic subsidence has occurred during prehistoric earthquakes along the Wasatch Front (Keaton, 1987).

Regional subsidence may result in inundation along lake and reservoir shores, causing damage to structures and injury or loss of life, and ponding of water in areas with a shallow water table, causing flooded basements and buried facilities (Smith and Richins, 1984). Regional subsidence may also adversely affect certain structures that require gentle gradients or horizontal floors, particularly wastewater-treatment facilities and sewer lines, preventing proper operation (Keaton, 1987). Subsidence typically extends only a short distance beyond the ends of the fault rupture. The maximum amount of subsidence should occur at the fault and gradually decrease away from the fault on the downdropped valley block.

Regional subsidence is a hazard in the Magna quadrangle along known faults, particularly those having evidence of movement during the last 10,000 years. Subsidence characteristics of the Wasatch fault zone have been modeled (Smith and Richins, 1984; Keaton, 1986; Chang and Smith, 1998; Solomon and others, 2004), and these studies show the greatest subsidence would occur nearest the fault zone and lessen farther away from the fault. Subsidence related to an earthquake on the Wasatch fault zone would also affect the shoreline of Great Salt Lake and, depending on the lake level at the time of the earthquake, could cause localized flooding. Although subsidence characteristics of the West Valley fault zone and the Oquirrh Mountain fault zone have not been studied in detail, a few generalizations can be made. Subsidence related to the West Valley fault zone would be greatest near the fault zone (northeast corner of the quadrangle), lessen east from the fault zone. Subsidence related to the Oquirrh Fault zone would not likely affect the area, which is located on the upthrown (footwall) side of the fault.

REFERENCES

Anderson L.R., Keaton J.R., Spitzley J.E., and Allen A.C., 1994, Liquefaction map for Salt Lake County, Utah, complete technical report: Utah Geological Survey Contract Report 94-9, 48 p.

Arabasz, W.J., Pechmann, J.C., and Brown, E.D., 1992, Observational seismology and the evaluation of earthquake hazards and risk in the Wasatch Front area, Utah, *in* Gori, P.L., and Hays, W.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-D, 36 p.

Bartlett, S.F., Ericksen, G., Leeflang, B., and Solomon, B.J., 2006, Probabilistic liquefaction potential and liquefaction-induced ground-failure maps for the urban Wasatch Front—Phase 3: Unpublished report to the U.S. Geological Survey, National Earthquake Hazards Reduction Program, Award 06HQGR0015, 158 p.

Bartlett, S.F., Olsen, M.J., and Solomon, B.J., 2005, Probabilistic liquefaction potential and liquefaction-induced ground-failure maps for the urban Wasatch Front - Phase 1: Unpublished report to the U.S. Geological Survey, National Earthquake Hazards Reduction Program, Awards 04HQGR0025 and 04HQGR0026, 197 p.

Black, B.D., Hecker, S., Jarva, J.L., Hylland, M.D., Christenson, G.E., and McDonald, G.N., 2003, Quaternary fault and fold database and map of Utah: Utah Geological Survey Map 193DM, 1:500,000 scale, compact disk.

Black, B.D., Mulvey, W.E., Lowe, M., and Solomon, B.J., 1995, Geologic effects, *in* Christenson, G.E., editor, The September 2, 1992 M_L 5.8 St. George earthquake: Utah Geological Survey Circular 88, p. 2–11.

Bolt, B.A., 1988, Earthquakes (Second edition): New York, W.H. Freeman and Company, 282 p.

Bryant, W.A., and Hart, E.W., 2007, Fault-rupture hazard zones in California—Alquist-Priolo earthquake fault zoning act with index to earthquake fault zones maps: California Geological Survey Special Publication 42, 38 p., digital version available online at ftp://ftp.consrv.ca.gov/

pub/dmg/pubs/sp/Sp42.pdf, accessed August 2010.

California Geological Survey, 2008, Guidelines for evaluating and mitigating seismic hazards in California: California Geological Survey Special Publication 117A, 98 p., digital version available online at http://www.conservation.ca.gov/cgs/shzp/webdocs/Documents/sp117.pdf, accessed August 2010.

Chang, W., and Smith, R.B., 1998, Potential for tectonically induced tilting and flooding by the Great Salt Lake, Utah, from large earthquakes on the Wasatch Fault, *in* Lund, W.R., editor, Proceedings volume, Basin and Range Province seismic-hazards summit: Utah Geological Survey Miscellaneous Publication 98-2, p. 128–138.

Christenson, G.E., Batatian, L.D., and Nelson, C.V., 2003, Guidelines for evaluating surface-fault-rupture hazards in Utah: Utah Geological Survey Miscellaneous Publication 03-6, 16 p.

Christenson, G.E., editor, 1995, The September 2, 1992 M_L 5.8 St. George earthquake: Utah Geological Survey Circular 88, 41 p.

Christenson, G.E., and Bryant, B.A., 1998, Surface-faulting hazard and land-use planning in Utah, *in* Lund, W.R., editor, Proceedings volume, Basin and Range Province seismic-hazards summit: Utah Geological Survey Miscellaneous Publication 98-2, p. 63–73.

Costa, J.E., and Baker, V.R., 1981, Surficial geology—building with the Earth: New York, John Wiley and Sons, 498 p.

dePolo, C.M., and Slemmons, D.B., 1990, Estimation of earthquake size for seismic hazards, *in* Krinitzsky, E.L., and Slemmons, D.B., editors, Neotectonics in earthquake evaluation: Geological Society of America Reviews in Engineering Geology Volume VIII, p. 1–28.

dePolo, C.M., and Slemmons, D.B., 1998, Age criteria for active faults in the Basin and Range Province, *in* Lund, W.R., editor, Proceedings volume, Basin and Range Province seismic-hazards summit: Utah Geological Survey Miscellaneous Publication 98-2, p. 74–83.

Eldredge, S.N., and Christenson, G.E., 2008, Earthquakes, *in* Utah natural hazards handbook: Utah Division of Homeland Security, Salt Lake City, Utah, p. 3–15.

Eldredge, S.N., and O'Brien, E.H., 2001, Photo essay of four Utah earthquakes 1921–1962: Utah Geological Survey Public Information Series 72.

Hays, W.W., and King, K.W., 1982, Zoning of earthquake shaking hazards along the Wasatch fault zone, Utah: Third International Earthquake Microzonation Conference, Seattle, Washington, v. 3, p. 1307–1318.

Hill, R.J., 1979, A liquefaction potential map for Cache Valley, Utah: Logan, Utah State University, unpublished M.S. thesis, 96 p.

International Code Council, 2009a, International building code: Country Club Hills, Illinois, 678 p.

International Code Council, 2009b, International residential code: Country Club Hills, Illinois, 870 p.

Keaton, J.R., 1986, Potential consequences of tectonic deformation along the Wasatch fault: Logan, Utah State University, Department of Civil and Environmental Engineering unpublished Final Technical Report prepared for the U.S. Geological Survey, 23 p.; published as Utah Geological Survey Contract Report 93-8, 1993.

Keaton, J.R., 1987, Potential consequences of earthquake-induced regional tectonic deformation along the Wasatch Front, north-central Utah, *in* McCalpin, J.P., editor, Proceedings of the 23rd Symposium on Engineering Geology and Soils Engineering: Boise, Idaho Department of Transportation, p. 19–34.

Keaton, J.R., Currey, D.R., and Olig, S.J., 1993, Paleoseismicity and earthquake hazards evaluation of the West Valley fault zone, Salt Lake City urban area, Utah: Utah Geological Survey Contract Report 93-8, 89 p.

Keller, E.A., and Blodgett, R.H., 2006, Natural hazards—Earth's processes as hazards, disasters, and catastrophes: Upper Saddle River, New Jersey, Pearson Prentice Hall, 395 p.

Magistrale, H., Olsen, K., and Pechmann, J., 2009, Construction and verification of a Wasatch Front community velocity model—Collaborative research with San Diego State University and the University of Utah: Final Technical Report to the U.S. Geological Survey National Earthquake Hazard Reduction Program, Award Nos. 05HQGR0006, 05HQGR0011, 06HQGR0009 and 06HQGR0012, 14 p.

Martin, G.R., and Lew, M., editors, 1999, Recommended procedures for implementation of DMG Special Publication 117, Guidelines for analyzing and mitigating liquefaction hazards in California: University of Southern California, Southern California Earthquake Center, 63 p.

McCalpin, J.P., 2009, Paleoseismology (second edition): San Diego, Academic Press, 848 p.

McDonald, G.N., and Ashland, F.X., 2008, Earthquake site conditions in the Wasatch Front urban corridor, Utah: Utah Geological Survey Special Study 125, 41 p., 1 plate, scale 1:150,000, compact disk.

National Research Council, 1985, Liquefaction of soils during earthquakes: Washington, D.C., National Academy Press, 240 p.

Reiter, L., 1990, Earthquake hazard analysis issues and insights: New York, Columbia University Press, 254 p.

Richter, C.M., 1938, An instrumental earthquake magnitude scale: Seismological Society of America Bulletin, v. 25, p. 1–32.

Richter, C.M., 1958, Elementary seismology: San Francisco, W.H. Freeman and Co., 768 p.

Robison, R.M., 1993, Surface-fault-rupture—A guide for land-use planning, Utah and Juab Counties, Utah, *in* Gori, P.L., editor, Applications of research from the U.S. Geological Survey program, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1519, p. 121–128.

Salt Lake County, 2010, Title 19, zoning, chapter 19.75, geologic hazards ordinance, Salt Lake County Municipal Code, Salt Lake County, Utah, codified through ordinance No. 1668, passed Feb. 2, 2010, (Supplement No. 17).

Seed, H.B., 1979, Soil liquefaction and cyclic mobility evaluation for level ground during earthquakes: Journal of the Geotechnical Engineering Division, American Society of Civil Engineers, v. 105 v. 2, p. 201–255.

Smith, R.B., and Arabasz, W.J., 1991, Seismicity of the Intermountain Seismic Belt, *in* Slemmons, D.B., Engdahl, E.R., Zoback, M.D., and Blackwell, D.D., editors, Neotectonics of North America: Boulder, Colorado, Geological Society of America, Decade Map Volume, p. 185–228.

Smith, R.B., and Richins, W.D., 1984, Seismicity and earthquake hazards of Utah and the Wasatch Front—Paradigm and paradox, *in* Hays, W.W., and Gori, P.L., editors, Proceedings of conference XXVI, workshop on "Evaluation of regional and urban earthquake hazards and risk in Utah": U.S. Geological Survey Open-File Report 84-763, p. 73–112.

Smith, R.B., and Sbar, M.L., 1974, Contemporary seismicity in the Intermountain seismic belt: Geological Society of America Bulletin, v. 85, p. 1205–1218.

Solomon, B.J., Biek, R.F., and Smith, T.W., 2007, Geologic map of the Magna quadrangle, Salt Lake County, Utah: Utah Geological Survey Map 216, scale 1:24,000.

Solomon, B.J., Storey, N., Wong, I., Silva, W., Gregor, N., Wright, D., and McDonald, G., 2004, Earthquake-hazards scenario for a M 7 earthquake on the Salt Lake City segment of the Wasatch fault zone, Utah: Utah Geological Survey Special Study 111DM, 59 p., 6 plates, scale 1:250,000.

Tinsley, J.C., Youd, T.L., Perkins, D.M., and Chen, A.T.F., 1985, Evaluating liquefaction potential, *in* Ziony, J.I., editor, Evaluating earthquake hazards in the Los Angeles region—An earth science perspective: U.S. Geological Survey Professional Paper 1360, p. 263–315.

University of Utah Seismograph Stations, 2010a, Personalizing the earthquake threat: Online, http://www.seis.utah.edu/lqthreat/perseq.shtml, accessed April 2010.

University of Utah Seismograph Stations, 2010b, Earthquake catalog of Utah, 1850 to 2009: Salt Lake City, Utah, University of Utah Seismograph Stations.

U.S. Geological Survey, 2008, National seismic hazard maps: Online, http://earthquake.usgs.gov/hazards/products/conterminous/2008/maps/, accessed August 2010.

U.S. Natural Resources Conservation Service, 2006, Soil survey geographic (SSURGO) database for Salt Lake area, Salt Lake County, Utah: Online, http://soildatamart.nrcs.usda.gov/, accessed September 2008.

Utah Seismic Safety Commission, 1995, A strategic plan for earthquake safety in Utah: Salt Lake City, Utah Seismic Safety Commission, 64 p.

Utah Seismic Safety Commission, 2008, Putting down roots in earthquake country—your handbook for earthquakes in Utah: Salt Lake City, Utah Seismic Safety Commission, 33 p.

Western States Seismic Policy Council, 2011, WSSPC Policy Recommendation 11-2—Active fault definition for the Basin and Range Province: Western States Seismic Policy Council, available online at http://www.wsspc.org/policy/files/Adopted/ADOPTED_PR11-2_BRFault.pdf, accessed June 2011.

Wong, I., Silva, W., Olig, S., Thomas, P., Wright, D., Ashland, F., Gregor, N., Pechmann, J., Dober, M., Christenson, G., and Gerth, R., 2002, Earthquake scenario and probabilistic ground shaking maps for the Salt Lake City metropolitan area, Utah: Utah Geological Survey Miscellaneous Publication 02-5, 50 p.

Yeats, R.S., Sieh, K., and Allen, C.R., 1997, The geology of earthquakes: New York, Oxford University Press, 568 p.

Youd, T.L, 1978, Major cause of earthquake damage is ground failure: Civil Engineering, v. 48, p. 47–51.

Youd, T.L., 1984, Geologic effects—liquefaction and associated ground failure: U.S. Geological Survey Open-File Report 84-760, p. 210–232.

Youd, T.L., and Perkins, D.M., 1978, Mapping liquefaction-induced ground failure potential: Journal of the Geotechnical Engineering Division, American Society of Civil Engineers, v. 104, p. 433–446.

Chapter 3
Flood Hazards

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Chapter 3: Flood Hazards

INTRODUCTION

Flooding is the overflow of water onto lands that are normally dry and is the most commonly experienced natural hazard (Keller and Blodgett, 2006). Damage from flooding includes inundation of land and property, erosion, deposition of sediment and debris, and the force of the water itself, which can damage property and take lives (Stauffer, 1992). Historically, flooding is the most prevalent and destructive (on an annual basis) geologic hazard affecting the Magna quadrangle. One of the most damaging floods to affect the Magna area occurred in 1922, when a flash flood issued from Little Valley Wash (figure 3.1) and destroyed a house in Magna, killing a young boy inside (Woolley, 1946). The federal Flood Control Act of 1946 allotted $222,000 for flood protection along the wash (United States of America Congress, 1946). Other examples of damaging floods include, but are not limited to: a flood on August 13, 1930, that filled 12 homes with mud (Woolley, 1946); floods on August 3 and 4, 1951, that inundated several Magna homes; July 26, 1954, flooding of more than 12 homes and businesses; and August 31, 1963, flooding that inundated several basements and caused more than $4,500 in damages. Additionally, in 1986, Great Salt Lake reached a historical peak elevation of 4211.85 feet (1283.78 m) (Harty and Christenson, 1988), within 4 feet (1.2 m) of the lowest elevation of the Magna quadrangle. Geologic evidence has shown that Great Salt Lake has reached an elevation of 4217 feet (1285 m), well within the limits of the Magna quadrangle, at least twice within the past 3000 years (Currey and others, 1984; Harty and Christenson, 1988).

Within the Magna quadrangle, the high flood hazard results from several factors. Several creeks capable of producing flooding are at least partially located within the quadrangle. These include two perennial creeks, Lee Creek and Coon Creek, and several smaller ephemeral drainages, including Little Valley Wash. All of these creeks eventually drain to Great Salt Lake, which is in close proximity to the quadrangle and also contributes to the high flood hazard.

Seasonal weather patterns that deliver moisture to northern Utah also contribute to the high flood hazard. Three types of floods typically occur in the study area: riverine (stream) floods, alluvial-fan flooding (including flash floods and debris flows), and sheetfloods (table 3.1). All three types of floods are associated with natural climatic fluctuations and may occur in combination with each other. The risk from flooding is significantly increased by wildfires because the destruction of roots results in a decrease of water infiltration and an increase in run-off and erosion. Human activities, such as placing structures and constrictions in flood plains or erosion-hazard zones, developing without adequate flood and erosion control, and poor watershed management practices (such as overgrazing or allowing indiscriminate off-road vehicle traffic) also increase the risk from flooding. Additionally, portions of the study area are subject to inundation in the event of an unintentional release of water from an engineered water-retention or conveyance structure (such as a dam canal) (table 3.1). During earthquakes, ground shaking, surface fault rupture, ground tilting, and landsliding can cause flooding if water tanks, reservoirs, pipelines, or aqueducts are ruptured, or if stream courses are blocked or diverted. Areas where such flooding may occur can be predicted to some extent by defining active faults (plate 2), active landslides, and potentially unstable slopes (plate 4). Damming of streams by landslides can cause upstream inundation and, if the dam subsequently fails, cause catastrophic downstream flooding (Schuster, 1987).

Figure 3.1. *Little Valley Wash. View northeast, downstream towards the town of Magna, Utah, March 8, 2010.*

METHODS AND SOURCES OF DATA

We used the Federal Emergency Management Agency (FEMA) National Flood Insurance Program Flood Insurance Rate Map (FIRM), as well as geologic mapping, to identify flood-hazard potential in the Magna quadrangle (Solomon and others, 2007; FEMA, 2009). Additionally, we used 1937, 1940, and 1965 U.S. Department of Agriculture aerial photographs (Agricultural Stabilization Conservation Service, 1937; Soil Conservation Service, 1940, 1965) (all 1:20,000-scale), and 2-meter bare earth Light Detection and Ranging (LiDAR) data (Utah Automated Geographic Reference Center, 2006) to examine past and present drainage patterns in the quadrangle.

Flood Insurance Rate Maps (FIRM)

The FIRM shows boundaries of expected 100- and 500-year floods (floods with a 1% and 0.2% probability of occurring in any given year, respectively) along selected drainages in the Magna quadrangle. Due to differences in scale and lack of common registration points between the FIRM and the 1:24,000-scale topographic map used as the base for this study, the FEMA 100-year flood boundaries shown on the accompanying map (plate 3) are approximate.

Table 3.1. *Flood types common in the Magna quadrangle, and their definition, most likely cause, and location.*

Flood Type		Definition	Most Likely Cause	Location
Stream		Runoff that exceeds the capacity of a stream's channel.	Rapid melt of snowpack and/or prolonged heavy rainfall.	Generally associated with major drainages. Lee Creek poses the highest threat from riverine flooding, with a historical peak stream flow of 165 cubic feet/second recorded in September of 2007 (U.S. Geological Survey, 2009). Coon Creek also poses a high risk, but no recorded peak stream-flow data exists. However, other smaller drainages may also contribute.
Alluvial fan*	Flash Floods	Sudden, intense, localized runoff that may exceed the capacity of a stream's channel.	Intense cloudburst rainfall that often accompanies summer convective thunderstorms.	Generally begins in the drainages of small- to large-sized watersheds and spreads out on the associated alluvial fan. The most damaging flash floods generally occur in small- to medium-sized watersheds characterized by ephemeral stream flow and normally dry stream channels. The 1922 Little Valley Wash flood was a flash flood.
	Debris Flows	Fast-moving slurries of mud, rock, organic matter, and water that flow down steep mountain channels and then spread out and come to rest on alluvial fans.	Rapid snowmelt or intense thunderstorm rainfall. Often has associated stream-flow flooding.	Begin in drainage basins and deposit on active alluvial fans.
Sheetfloods		A broad expanse of moving storm water that spreads as a thin, continuous, relatively uniform sheet over a large area and is not concentrated into well-defined channels.	Occurs before runoff is sufficient to promote channel flow, or after a period of intense rainfall.	Across an alluvial fan after the flood waters have deposited some of their sediment load and begin to slow down and spread out across the lower (toe) part of the fan surface, or as runoff from moderate to steep slopes during intense cloudburst storms.
Unintentional Water Release		An unintentional release of water due to the failure of a water-retention or conveyance structure, which may occur with little warning.	May be caused by earthquake or other factors related to climate or construction.	Downstream from water-retention or conveyance structures. Only two high-hazard dams lie within six miles of the Magna quadrangle (the dams are located in the Copperton quadrangle directly to the south), but flows are not expected to affect the quadrangle.

*Alluvial fans are relatively flat to moderately sloping deposits of loose to weakly consolidated sediment which have the shape of a fan and are deposited by a stream at a topographic break, such as the base of a mountain front, escarpment, or valley side (National Research Council, 1996).

FIRM coverage in the Magna quadrangle is limited to several large perennial (Lee Creek and Coon Creek) and ephemeral drainages (such as Little Valley Wash) and canals. Portions of the Magna quadrangle not covered by the FIRM contain numerous smaller ephemeral streams, alluvial fans, and other areas subject to periodic flooding, chiefly as a result of cloudburst storms.

FEMA, through its National Flood Insurance Program (NFIP), makes federally subsidized flood insurance available to qualified individuals residing in participating communities. FIRMs are legal documents that govern the administration of the NFIP. Property owners should consult the appropriate FIRM directly when considering the purchase of NFIP flood insurance.

Geologic Mapping

We used the distribution of geologically young flood-related deposits shown on recently completed geologic mapping (Solomon and others, 2007) to identify flood-prone areas and their relative susceptibility (very low, low, moderate, and high) to flooding throughout the Magna quadrangle (plate 3). Large bedrock areas in the Oquirrh Mountains, on the western boundary of the quadrangle, were not assigned a flood-hazard category, because flooding in these areas will likely be restricted to drainages. Individual drainages were not mapped due to the topographic complexities and scale limitations of the area. Table 3.2 describes the four flood-hazard categories and shows the geologic units generally associated with each category.

USING THIS MAP

The flood-hazard map (plate 3) shows drainages covered by the FIRM and other potential flood-hazard areas identified using geologic data. However, because intense cloudburst storms can create a potential for flash floods, debris flows, and sheetfloods anywhere in the study area, even locations outside of identified potential flood-hazard areas could be subject to periodic flooding. The map is designed for use in general planning to indicate the need for site-specific geotechnical/geologic-hazard investigations. The map also shows where existing developments are within potential flood-hazard areas and therefore may require remedial flood-hazard-reduction measures. An evaluation of flood mitigation measures already in place and their likely effectiveness is beyond the scope of this study.

The International Building Code (IBC; International Code Council, 2009) states that construction of new buildings and structures and additions to existing buildings and structures must be designed and constructed to resist the effects of flood hazards and flood loads. These requirements apply to construction in flood-hazard areas (zone A) identified on the FIRM by FEMA or other adopted flood-hazard maps. Appendix G of the IBC outlines development requirements, flood-resistant construction, and required permit information. Adoption and enforcement of IBC appendix G is left up to local jurisdictions.

The UGS recommends retaining a geotechnical engineering firm to perform a standard geotechnical/geologic-hazard investigation for all development in the Magna quadrangle. The potential for flooding along with all other potential geologic hazards should be addressed in these investigations. The investigation should establish the type and likelihood of flooding and recommend measures to reduce the hazard.

MAP LIMITATIONS

Plate 3 is based on limited geological, geotechnical, and hydrological data. The quality of the map depends on the quality of these data, which vary throughout the study area. The mapped boundaries of the flood-hazard categories are approximate and subject to change with additional information. The flood hazard at any particular site may be different than shown because of geological and hydrological variations within a map unit, gradational and approximate map-unit boundaries, and the generalized map scale. Small, localized areas of higher or lower flood hazard may exist within any given hazard area, but their identification is precluded because of limitations of map scale. Additionally, the flood-hazard map may not include areas that are subject to inundation from shallow groundwater (consult plate 10 for shallow groundwater information), is not intended for use at scales other than 1:24,000, and is designed for use in general planning and design to indicate the need for site-specific geotechnical/geologic-hazard investigations, which are required to produce more detailed flood-hazard information.

HAZARD REDUCTION

Early recognition and avoidance of areas subject to flooding are the most effective means of reducing flood hazard. Flooding investigations that identify possible types and sources of flooding for specific areas are recommended for all hazard categories (high, moderate, low, and very low). For areas of potential stream flooding and debris flows, proper identification of the hazard areas through detailed mapping, and qualitative assessment of the hazard are the first step in hazard reduction (Giraud, 2004, 2005). The National Research Council (1996), FEMA (1999), and Giraud (2005) provide guidance for evaluating flood and debris-flow hazards on alluvial fans. The stream flooding hazard assessment should determine the active flooding area, frequency of past events, and potential inundation and flow depths. An assessment of debris flow hazards should determine active depositional areas, the frequency and volume of past events, and sediment burial

Table 3.2. Flood-hazard categories based on the genesis of geologic deposits mapped by the UGS.

Hazard Category	Geologic Units[1]	Description	Hazard Type	Comments[2]
High	Qac, Qaf1, Qafy, Qaly, Qlay, Qldy, Qlmy, Qly	Active flood plains and low terraces along perennial and larger ephemeral streams, active alluvial fans, lacustrine deposits associated with Great Salt Lake, and young deltaic deposits, which still experience flooding related to shallow ground water, and streams that flow in the area.	Riverine flood, flash flood, debris flow, sheetflood, lake flood	May include other units, in whole or part that are located in major mapped drainages, gravel pits that intersect drainages, and near alluvial fans, and young lacustrine and deltaic deposits that experience flooding related to shallow ground water and streams that flow in the area.
Moderate	Qafb, Qafp, Qafo, Qalb, Qat_2, Qc, Qll, Qmsy, Qmt, QTaf	Stream channels, flood plains, and low terraces along smaller, normally dry streams with comparatively small drainage basins subject to flooding during infrequent cloudburst storms, older alluvial-fan deposits, lagoon-fill deposits located in closed depressions, and colluvial and landslide deposits on mountain slopes and along mountain range fronts.	Flash flood, debris flow	May include other units, in whole or part that are near (but not in) drainages, gravel pits that intersect re-graded or concealed drainages (no longer visible on current aerial photographs or LiDAR), and topographic depressions with the potential to collect water. Also includes alluvial fans that are "disconnected" from their drainages (drainages have been re-graded or concealed by historical human activities).
Low	Qldb, Qlgb, Qlgbp, Qlgp, Qlmbp, Qlsb, Qlsbp, Qlsp	Valley bottoms with minor ephemeral drainages, subject to infrequent flooding from adjacent upland areas during cloudburst storms.	Chiefly sheetflood, flash flood	May include other units, in whole or part that are located on steep slopes and ridge tops where flooding is restricted to drainages. Flood hazards related to individual drainages were not mapped due to scale limitations.
Very Low	Qap_2	Pediment-mantle alluvium on ridge tops.	Sheetflood	No other units included.

[1]Refer to Solomon and others (2007) for a description of map units.

[2]Categories may include small bedrock knobs and fill deposits that were included into units based on topography.

depths. The level of detail for a hazard assessment depends on several factors, including the type, nature, and location of the proposed development; the geology and physical characteristics of the drainage basin, channel, and alluvial fan; the history of previous flooding and debris-flow events; the level of risk acceptable to property owners and land-use regulators; and proposed risk-reduction measures.

Avoidance of areas subject to flooding may not always be a viable or cost-effective hazard-reduction option, especially for existing developments. Other techniques are available to reduce potential flood damage. These may include, but are not limited to, source-area stabilization, engineered protective structures, such as debris basins or detention basins; flood and debris-flow warning systems; and floodproofing. Some of these techniques can be expensive, and their cost versus benefit ratio should be carefully evaluated. Regarding sheetflooding, a properly sized and integrated system of street and storm drains is usually adequate to mitigate this hazard. To adequately reduce risks from flooding (other than sheetfloods but including debris flows), engineered flood- and debris-retention basins or other significant and often costly flood-control structures may be required. Although some cities and counties attempt to address these issues in the subdivision approval process, problems arise because these structures: (1) benefit the community as well as individual subdividers, (2) typically are expensive, (3) require reliable maintenance and periodic sediment removal, (4) may divert flows and increase hazards in adjacent areas, and (5) must often be located in areas not owned or controlled by an individual subdivider (Giraud, 2004, 2005). Because of this, risk reduction from flooding and debris flows may be considered a government public works responsibility. This is particularly true in urban settings where hazard areas encompass more than one subdivision and include pre-existing development already permitted by a city or county.

Site-specific geotechnical/geologic-hazard investigations that address earthquake and slope-failure hazards should be completed prior to construction of all major water-retention structures or conveyance systems so that hazard-reduction measures can be recommended. To prepare for water-system breaks, shut-off valves and emergency response/repair plans should be in place. For existing facilities, investigations can evaluate the possible locations and extent of flooding and recommended drainage modifications to prevent floods or divert flood waters. Potential flooding from diversion of stream courses is more difficult to evaluate, but should be considered in hazards evaluations for critical facilities.

Where development is proposed in areas identified on the flood-hazard map (plate 3) as having a potential flood hazard, a site-specific geotechnical/geologic-hazard investigation should be performed early in the project design phase. A site-specific investigation can establish whether a flood and/or debris-flow hazard is present at a site and provide appropriate design recommendations. If hazard-reduction techniques are not implemented, risk may be accepted, but an informed decision is only possible if the flood potential and consequences are clearly understood and disclosed. If the risk is significant but acceptable, the individual structures may be insured, either through NFIP, if eligible in participating communities, or by a private insurance provider.

REFERENCES

Agricultural Stabilization Conservation Service, 1937, Aerial photography, Project AAL frames 2-64 through 2-73, 2-82 through 2-91, 3-18 through 3-28, and 3-35 through 3-45, dated 9-19-1937 and 9-21-1937, black and white, approximate scale 1:20,000.

Currey, D.R., Atwood, G., and Mabey, D.R., 1984, Major levels of Great Salt Lake and Lake Bonneville: Utah Geological and Mineral Survey Map 733, scale 1:750,000.

Federal Emergency Management Agency, 1999, Guidelines for determining flood hazards on alluvial fans: Federal Emergency Management Agency, 23 p.

Federal Emergency Management Agency, 2009, National Flood Insurance Program flood insurance rate map, Salt Lake County, Utah and incorporated areas: Federal Emergency Management Agency, Panel 275, scale 1"=2,000', Online, http://msc.fema.gov, accessed December 3, 2009.

Giraud, R.E., 2004, Geologic hazards of Monroe City, Sevier County, Utah: Utah Geological Survey Special Study 110, 51 p., accompanying compact disk contains GIS data, appendix A, and plates.

Giraud, R.E., 2005, Guidelines for the geologic evaluation of debris-flow hazards on alluvial fans in Utah: Utah Geological Survey Miscellaneous Publication 05-6, 16 p.

Harty, K.M., and Christenson, G.E., 1988, Flood hazard from lakes and failure of dams in Utah: Utah Geological and Mineral Survey map 111, 8 p. pamphlet, 1 plate, scale 1:750,000.

International Code Council, 2009, International building code: Country Club Hills, Illinois, International Code Council, 678 p.

Keller, E.A., and Blodgett, R.H., 2006, Natural hazards—Earth's processes as hazards, disasters, and catastrophes: Upper Saddle River, New Jersey, Pearson Prentice Hall, 395 p.

National Research Council, 1996, Alluvial fan flooding: Washington, D.C., National Academy Press, 172 p.

Schuster, R.L., 1987, Landslide damming of mountain streams: Geological Society of America, Abstracts with Programs, v. 19, no. 5, p. 332.

Soil Conservation Service, 1940, Aerial photography, Project COI frames 1-18 through 1-25, dated 7-29-1940, black and white, approximate scale 1:20,000.

Soil Conservation Service, 1965, Aerial photography, Project AAL 2FF frames 7-17, 58-67, and 83-91, dated 7-26-1965, black and white, approximate scale 1:20,000.

Solomon, B.J., Biek, R.F., and Smith, T.W., 2007, Geologic map of the Magna quadrangle, Salt Lake County, Utah: Utah Geological Survey Map 216, scale 1:24,000.

Stauffer, N., 1992, Floods, *in* Eldredge, S.N., editor, Utah natural hazards handbook: Salt Lake City, Utah Division of Comprehensive Emergency Management, p. 42–45.

United States of America Congress, 1946, Flood Control Act of 1946: Washington D.C., United States of America, 79th Congress, 2nd Session, House Document 562.

U.S. Geological Survey, 2009, Peak stream flow for Utah: Online, http://waterdata.usgs.gov/ut/nwis, accessed October 21, 2009.

Utah Automated Geographic Reference Center, State Geographic Information Database, 2006, 2 meter bare earth LiDAR: Utah Automated Geographic Reference Center, Online, http://gis.utah.gov/elevation-terrain-data/2-meter-lidar, accessed March 2009.

Woolley, R.R., 1946, Cloudburst floods in Utah, 1850–1938: U.S. Geological Survey Water Supply Paper 994, 128 p., 23 plates.

Chapter 4
Landslide Hazards

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Chapter 4: Landslide Hazards

INTRODUCTION

Landslide is a general term that refers to the gradual or rapid movement of a mass of rocks, debris, or earth down a slope under the force of gravity (Neuendorf and others, 2005). The term covers a wide variety of mass-movement processes, and includes both deep-seated and shallow slope failures. The moisture content of the affected materials when a slope fails may range from dry to saturated. However, moisture content affects the strength of most deposits susceptible to landslides, and is often a triggering mechanism.

Landslides can be both damaging and deadly. The U.S. Geological Survey (USGS) estimates that in the United States, landslides cause on average $1–2 billion in damages and more than 25 deaths each year (USGS, 2009a). Elliott and Harty (2010) compiled a map of over 22,000 landslides statewide in Utah. Schuster (1996) reported that the multiple landslides that occurred in Utah from 1983 to 1984 resulted from a combination of heavy precipitation in the fall and rapid melting of a record snowpack in the spring. The 1983 to 1984 Utah landslides are among the three most economically devastating landsliding events in the United States in recent decades. The total estimated direct cost for the 1983 to 1984 Utah landslides was more than $310 million (Anderson and others, 1984; B.N. Kaliser, personal communication, 1984, in Schuster, 1996). The April 1983 Thistle landslide in Utah County, with an estimated cost in excess of $200 million, is recognized in terms of both direct and indirect costs as the most expensive individual landslide in North American history (Schuster, 1996; USGS, 2009b).

Three broad factors, acting either individually or in combination, contribute to landslides (Varnes, 1978; Wieczorek, 1996): (1) an increase in shear stress, (2) low material strength, and (3) a reduction of shear strength. Common factors that increase shear stress include adding mass to the top of a slope, removing support from the toe of a slope, transient stresses associated with earthquakes and explosions, and the long-term effects of tectonic uplift or tilting. Low material strength in rock or soil typically reflects the inherent characteristics of the material or are influenced by discontinuities (such as joints, faults, bedding planes, and desiccation fissures). Factors that reduce shear strength include both physical and chemical weathering, and the addition of water to a slope, which increases pore-water pressures and reduces the effective intergranular pressure within the slope materials.

Although one or more of the above causes may make a rock or soil mass susceptible to failure, a trigger is required for landsliding to occur (Varnes, 1978; Cruden and Varnes, 1996). A trigger is an external stimulus or event that initiates landsliding either by increasing stresses or reducing the strength of slope materials (Wieczorek, 1996). Common landslide triggers in Utah include both static and dynamic conditions. Static conditions include intense rainfall or prolonged periods of above normal precipitation, rapid snowmelt, and rapid erosion. Dynamic conditions include earthquake and other shaking. Although frequently obvious, some triggers are subtle and not readily apparent. For example, a nearly imperceptible combination of weathering and gradual erosional undercutting can eventually cause landsliding.

Cruden and Varnes (1996) grouped all landslides into one of five types based on their mode of movement: fall, topple, slide, spread, and flow (figure 4.1). The characteristics of the material that failed, the rate of movement, the state of activity, and the style of failure allow further subdivision and description of the various landslide types.

In the Magna quadrangle, the five landslide types are typically associated with different geologic materials, failure mechanisms, and hazard-reduction techniques, and their hazard potential is mapped using different methods. Falls and topples are most common in bedrock, and their hazard potential is mapped and described in the Rock-Fall Hazards chapter of this report. Spreads are commonly associated with liquefaction-induced landsliding, termed lateral spreading, and are most often caused by earthquake ground shaking. Susceptibility to lateral spreading and other types of liquefaction is mapped and discussed in the Liquefaction Hazards section of the Earthquake Hazards chapter of this report. A specific type of flow, debris flow, is commonly found on alluvial fans at canyon mouths, and the hazard potential related to debris flows is mapped and discussed in the Flood Hazards section of this report. In this section, we restrict the term landslides to the type of landslide referred to by Cruden and Varnes (1996) as slides (figure 4.1).

A slide is the downslope movement of a soil or rock mass occurring dominantly on surfaces of rupture or on relatively thin zones of intense shear strain (Cruden and Varnes, 1996). Slides may be rotational or translational (figure 4.2). Rotational slides have curved, concave rupture surfaces, which may be either shallow or deep seated, along which the slide mass may move, sometimes with little internal disruption. Because of the curved rupture surface (figure 4.3), the head of a rotational slide commonly tilts backward toward the slide's main scarp. Rotational slides may be very slow to rapid and dry to wet, although most occur in the presence of at least

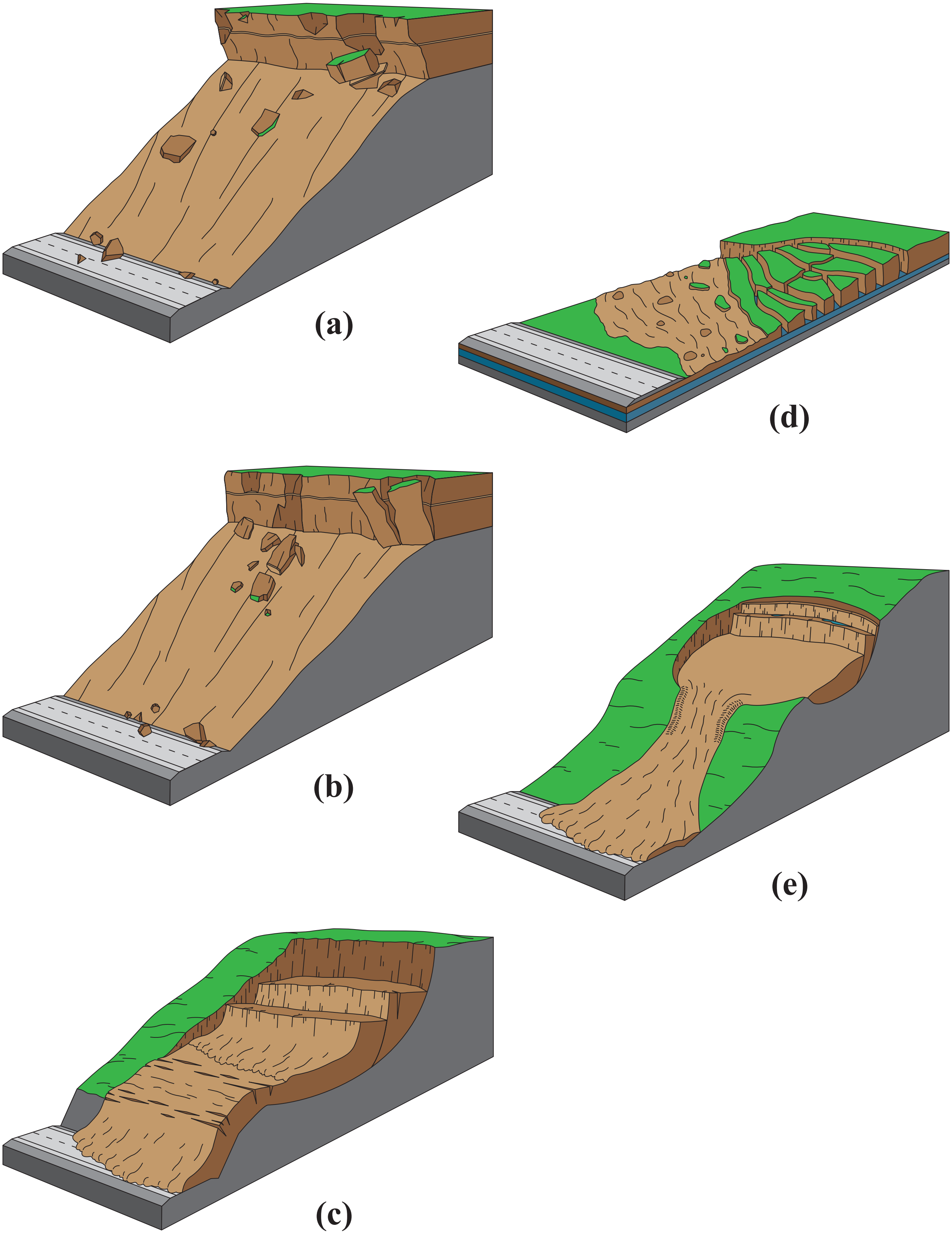

Figure 4.1. *Types of landslides: (a) fall, (b) topple, (c) slide, (d) spread, and (e) flow.*

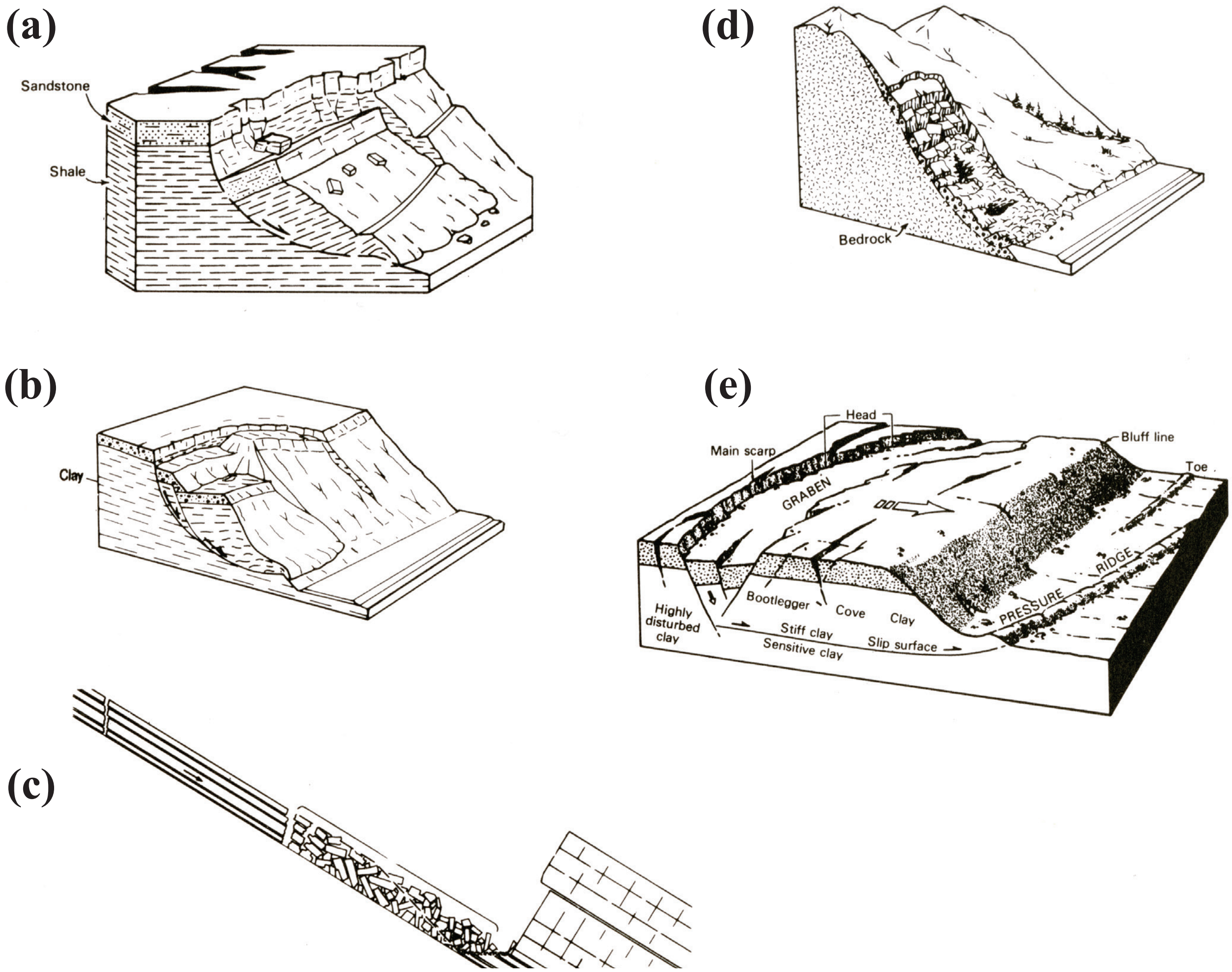

Figure 4.2. *Examples of rotational and translational slides: (a) rotational rock slide, (b) rotational earth slide, (c) translational rock slide, (d) translational debris slide, (e) translational earth slide (from Cruden and Varnes, 1996; reprinted with permission of the Transportation Research Council).*

some groundwater. Rotational slides may transition to an earth flow at their toes (figure 4.3). Translational slides move along planar or gently undulating shear surfaces and typically slide out over the original ground surface (figure 4.2; Cruden and Varnes, 1996). Translational slides often utilize discontinuities, such as bedding planes, joints, or faults as a surface of rupture, and if the slide plane is long enough and material moist enough, may transition into a flow. Movement of translational slides range from very slow to rapid.

Triggering mechanisms for slides vary and in some cases may not be readily discernable; however, periods of above-average precipitation are particularly effective in triggering slope failures in Utah (Schuster, 1996; Black and others, 1999). Although plentiful under static (non-earthquake) conditions, both rotational and translational slides commonly accompany earthquakes with Richter magnitudes greater than 4.5 (Keefer, 1984). For example, the September 2, 1992, M 5.8 St. George earthquake caused a large, destructive translational landslide near Springdale, Utah, 27 miles (43 km) from the earthquake epicenter, that destroyed three houses and a water tank, threatened several other structures, and closed State Route 9 (Jibson and Harp, 1995).

All of the 11 landslides identified in the Magna quadrangle (plate 4) are early Holocene or late Pleistocene in age, although they may have experienced historical movement (Solomon and others, 2007). Nine of the landslides occur near the southwest corner of the quadrangle and have surfaces of rupture in the tuffaceous Jordan Narrows unit of the Tertiary Salt Lake Formation (Tsl), which undermined old alluvial-fan deposits (QTaf) (figure 4.4). The northern of these nine landslides is a rotational landslide (Solomon and others, 2007). The eight southernmost landslides are rotational landslides that transition to earth flows. Near the center of the western quadrangle boundary is a rotational landslide, associated with thin deposits of colluvium and older alluvium overlying the Permian and Pennsylvanian Kessler Canyon Formation. This landslide has historically threatened an Alliant Techsystems water tank (Jon Hermance, Alliant Techsystems, personal communication, 2009). The northernmost landslide mapped in the quadrangle is a translational landslide that transitions into a flow and resulted from failure of Lake Bonneville gravel and sand that undermined the overlying fill (Solomon and others, 2007).

METHODS AND SOURCES OF DATA

To compile the landslide susceptibility map (plate 4), we used recent geologic mapping (Solomon and others, 2007); a statewide landslide map compilation (Elliott and Harty, 2010); field observations; 1937, 1940, and 1965 U.S. Department of Agriculture aerial photographs (Agricultural Stabilization Conservation Service, 1937; Soil Conservation Service, 1940, 1965) (all 1:20,000-scale); and 2-meter bare-earth Light Detection and Ranging (LiDAR) data (Utah Automated Geographic Reference Center, State Geographic Information Database, 2006). We used a digital elevation model (DEM) derived from the LiDAR data to generate shaded relief (hillshade) and slope maps. We used recent geologic mapping, a statewide landslide map compilation, field observations, aerial photography analysis, and hillshade maps to identify landslides and landslide-prone materials. The slope maps identify moderately to steeply sloping areas (defined as slopes greater than 10 degrees) that are generally more susceptible to landsliding than less steep slopes.

We classified landslide susceptibility as high, moderate, or low. As described in table 4.1, the high category consists of mapped landslides, geologic units that have experienced previous landsliding as identified by Solomon and others (2007) and this study, and areas identified by this study as possible landslides or highly susceptible to future landslide movement. We identified possible landslides and other highly susceptible areas (defined by highly disturbed ground not associated with human disturbance) by aerial photography analysis. We then verified these areas using LiDAR-derived hillshade maps, followed by field examination. The field observations indicated that many of these areas contain landslides too small to show at the mapped scale (1:24,000) and that they likely experienced landsliding and/or creep.

We define moderate landslide susceptibility as occurring in areas with slopes greater than 10 degrees in geologic units with no known prior landsliding. Because only 11 landslides have been individually identified in the quadrangle, a statistical analysis of the landslide slope angles for various geologic units was not possible. Consequently, we chose a slope angle of greater than 10 degrees based on three factors. First, all landslides mapped in the quadrangle are at least partially located on slopes of 10 degrees or more, and nine of the land-

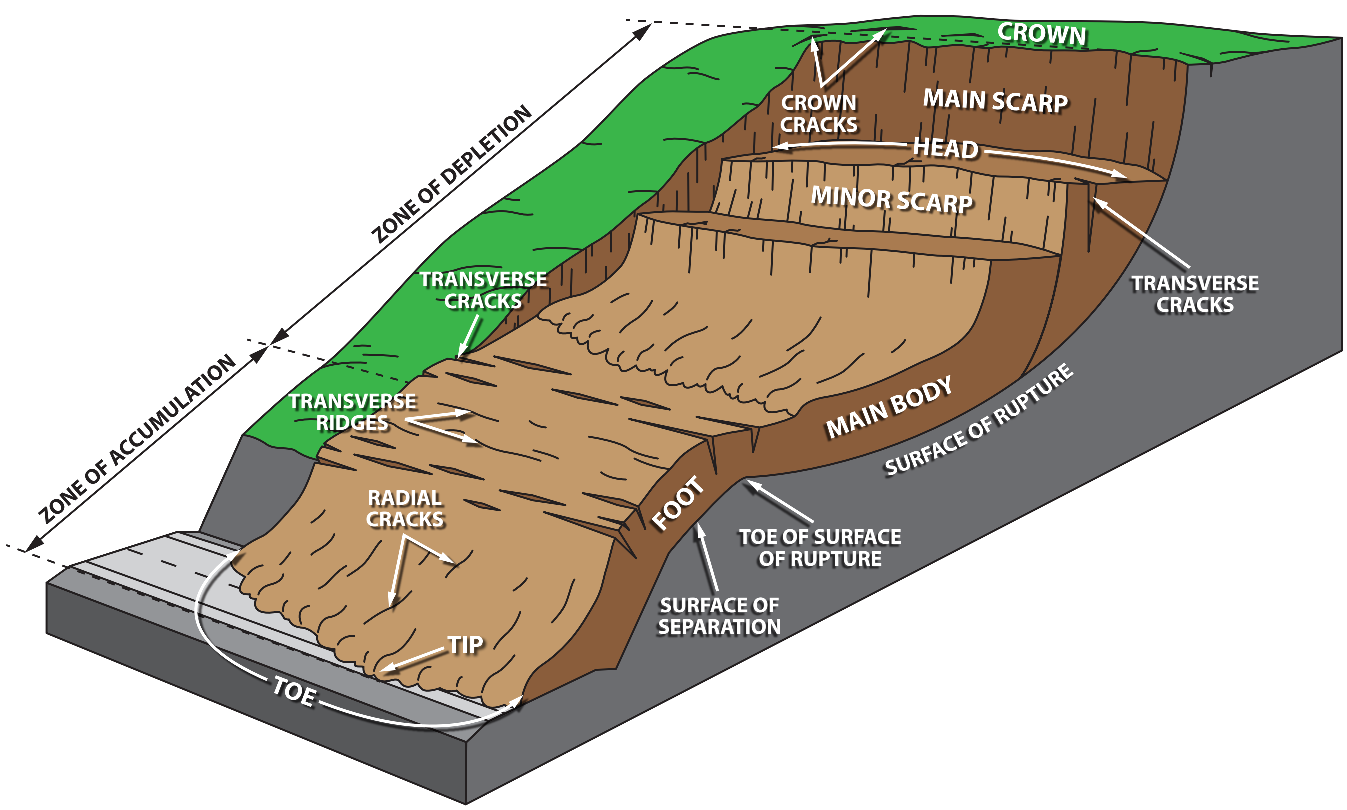

Figure 4.3. *Block diagram of an idealized complex landslide, with an earth slide near the top (same region as the "zone of depletion") and an earth flow near the toe (same region as the "zone of accumulation").*

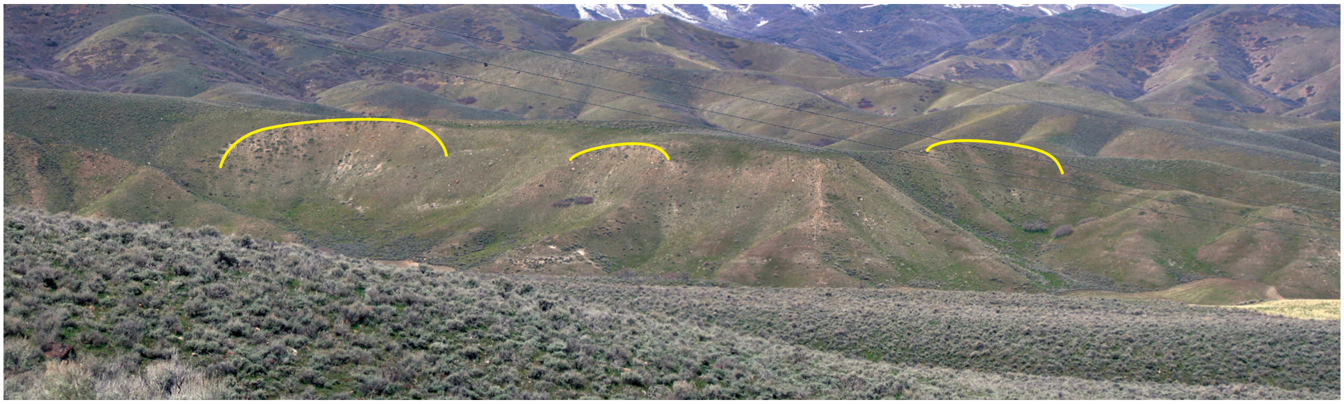

Figure 4.4. *West view of landslides (yellow lines show scarps) in Harkers Canyon associated with the Jordan Narrows unit of the Salt Lake Formation. Photo taken on April 27, 2009.*

slides have more than half of their area located on slopes of 10 degrees or more. Second, 10 degrees is generally the angle that separates the valley floor from the mountainous areas of the quadrangle, where landslides are most likely to occur. Third, similar angles have been used in other landslide evaluation and susceptibility investigations to define critical slope. For example, Giraud and Shaw (2007) used slope angles between 7 and 18 degrees to define the slope-angle threshold for the statewide landslide susceptibility map. In addition, Hylland and others (1995) used 9 degrees as the lowest critical slope angle for their evaluation of landslides in western Wasatch County.

We define low landslide susceptibility as areas with slope less than 10 degrees for all geologic units, except where field observations identified small landslides or creep deposits. We applied this threshold so that the valley floor, including geologic units highly susceptible to landsliding elsewhere, reflected the low landslide hazard. All landslide-susceptibility categories and their general occurrence are described in table 4.1.

Although the addition of earthquake shaking increases the potential for slope failure in susceptible material, the relative landslide susceptibility of the slope material does not change. For example, slopes mapped on plate 4 with moderate landslide susceptibility are more likely to fail during an earthquake than under static conditions; however, slopes with moderate landslide susceptibility are less likely to fail than slopes with a high susceptibility under static and/or dynamic conditions.

USING THIS MAP

The landslide-susceptibility map (plate 4) shows areas of relative landslide susceptibility and indicates where site-specific

Table 4.1. *Criteria to define landslide-susceptibility categories in the Magna quadrangle.*

<table>
<tr><th colspan="2">Landslide-Susceptibility Category</th><th>Criteria</th></tr>
<tr><td rowspan="2">High</td><td>Landslides</td><td>Landslides and their source areas as identified by Solomon and others (2007) and one landslide identified by this study (Alliant Techsystems water tank landslide).</td></tr>
<tr><td>Other high hazard areas</td><td>Areas identified by this study as possible landslides or highly susceptible to future landslide movement. Also, geologic units (Solomon and others, 2007) that have experienced previous landsliding in the quadrangle, including: Qlgb overlain by Qf (northern portion of quadrangle), Tsl in areas of steep slope (greater than 10 degrees), portions of PIPok where variations in the unit and/or differential weathering create less stable slopes, and QTaf overlying Tsl (southern portion of the quadrangle). Identified based on field observations, aerial photography analysis, geology, and/or topography.</td></tr>
<tr><td colspan="2">Moderate</td><td>Areas with slope greater than 10 degrees in geologic units with no known prior landsliding.</td></tr>
<tr><td colspan="2">Low</td><td>Areas with slope less than 10 degrees.</td></tr>
</table>

slope-stability conditions (material strength, orientation of bedding and/or fractures, groundwater conditions, and erosion or undercutting) should be evaluated prior to development. Landslide-hazard investigations must be interdisciplinary in nature and performed by qualified, experienced geotechnical engineers and engineering geologists working as a team. The level of investigation needed at a given site depends on the relative hazard and the nature of the proposed development (structure type, size, and placement; required cutting and filling; and changes in groundwater conditions). A valid landslide-hazard evaluation must address all pertinent conditions that could affect, or be affected by, the proposed development, including earthquake ground shaking. This can only be accomplished through the proper identification and interpretation of site-specific geologic conditions and processes (Hylland, 1996). Conditions that may affect a nearby site, although not directly on it, must also be considered.

The analysis of natural and modified slopes for static and/or seismic stability is a challenging geotechnical problem. Blake and others (2002) consider the following steps as required for a proper static slope stability analysis:

Accurate characterization of:

1. Surface topography,
2. Subsurface stratigraphy,
3. Subsurface water levels and possible subsurface flow patterns,
4. Shear strength of materials through which the failure surface may pass,
5. Unit weight of the materials overlying potential failure planes.

The stability calculations are then carried out using an appropriate analysis method for the potential failure surface being analyzed. A seismic slope-stability analysis requires consideration of each of the above factors for static stability, as well as characterization of:

- Design-basis earthquake ground motions at the site, and
- Earthquake shaking effects on the strength and stress-deformation behavior of the soil, including pore pressure generation and rate effects.

Although Blake and others (2002) consider all of the above factors vital for a proper slope stability analysis, they note that some are more easily characterized than others. Two factors, subsurface stratigraphy/geologic structure and soil shear strength, are particularly challenging to accurately characterize.

Additionally, Utah Geological Survey Circular 92, *Guidelines for Evaluating Landslide Hazards in Utah* (Hylland, 1996), recommends minimum standards for performing landslide-hazard evaluations in Utah. Circular 92 outlines a phased approach to slope-stability investigations, beginning with a geologic evaluation and progressing through reconnaissance and detailed geotechnical-engineering evaluations as needed based on the results of the previous phase. Black and others (1999) and Blake and others (2002) provide additional guidance for evaluating landslide hazards. Minimum UGS recommendations for site-specific investigations for each landslide-susceptibility category in the Magna quadrangle, in accordance with UGS Circular 92, are shown in table 4.2.

Salt Lake County's Zoning Ordinance Code prohibits development (including clearing, excavating, and grading) on slopes exceeding 30% and sets aside these areas as natural private or public open space (Salt Lake County, 2010). Also, all roads are restricted from crossing slopes between 30–50% unless they meet specific requirements and gain authorization (Salt Lake County, 2010).

While it is possible to classify relative landslide hazard in a

Table 4.2. *Recommended requirements for site-specific landslide-hazard investigations in the Magna quadrangle.*

Landslide Susceptibility	Recommended Site-Specific Investigation
High	Detailed engineering geologic and geotechnical-engineering investigation necessary. Predevelopment stabilization recommended for historical and geologically young (Holocene and late Pleistocene) landslides.
Moderate	Geologic evaluation and reconnaissance-level geotechnical-engineering investigation necessary; detailed engineering geologic and geotechnical-engineering investigation may be necessary.
Low	Geologic evaluation and reconnaissance-level geotechnical-engineering investigation necessary; detailed geotechnical-engineering investigation generally not necessary.

general way on the basis of material characteristics and critical slope inclinations, landslides ultimately result from the effects of site-specific conditions acting together to drive the slope toward failure. For that reason, all development in areas of sloping terrain where modifications to natural slopes will be significant or where landscape irrigation or onsite wastewater disposal systems may cause groundwater levels to rise (Ashland, 2003; Ashland and others, 2005, 2006), require a site-specific geotechnical/geologic-hazard investigation to evaluate the effect of development on slope stability.

MAP LIMITATIONS

The landslide-susceptibility map (plate 4) is based on limited geological, geotechnical, and hydrological data. The quality of the map depends on the quality of these data, which vary throughout the study area. The mapped boundaries between susceptibility categories are approximate, gradational, and subject to change with additional information. Landslide susceptibility at any particular site may be different than shown because of geological and hydrological variations within a map unit, gradational and approximate map-unit boundaries, and the generalized map scale. Small, localized areas of higher or lower landslide susceptibility are likely to exist within any given map area, but their identification is precluded because of the effects of unconsidered factors (such as a detailed analysis of critical slope angles for the various geologic units present in the quadrangle), the limitations of the map scale, and the relatively sparse data. The landslide-susceptibility categories do not consider hazards caused by cuts, fills, or other alterations to the natural terrain. The landslide-susceptibility map is not intended for use at scales other than 1:24,000, and is designed for use in general planning to indicate the need for site-specific geotechnical/geologic-hazard investigations, which are required to produce more detailed information and should be conducted by qualified professionals. Mapped landslide hazards indicate only the source zones of landslides (the parts of slopes that may fail). This map does not show how far downslope the failed material may travel before stopping. Proposed development in areas downslope of landslide source zones should consider this in site-specific geotechnical/geologic-hazard investigations.

HAZARD REDUCTION

As with most geologic hazards, early recognition and avoidance are the most effective ways to mitigate landslide hazards. Proper planning and avoidance are made possible if landslide-prone areas are identified early in the planning and design process (Black and others, 1999). However, avoidance may not always be a viable or cost-effective hazard-reduction option, especially for existing developments. Other engineering techniques are available to reduce potential landslide hazards. Care in site grading, with proper selection and compaction of fills and engineering of cut slopes, is necessary for successful hillside development. Careful attention to site drainage and dewatering of shallow groundwater or ponded surface water, when necessary, can stabilize slopes and existing landslides. Retaining structures at the toe of landslides and mechanical stabilization using tiebacks or other means that penetrate the landslide mass, pinning it to underlying stable material, may help stabilize existing landslides. Other techniques used to reduce landslide hazards include bridging, weighting, or buttressing slopes with compacted earth fills and installing landslide warning systems (Keller and Blodgett, 2006).

Where development is proposed in areas identified on the landslide-susceptibility map as having a potential for slope failure, a phased geotechnical/geologic-hazard site-specific investigation should be performed early in project design. A site-specific investigation can establish whether the necessary conditions for slope failure are present at a site. If such conditions do exist, the geotechnical consultant should provide appropriate design, mitigation, and/or construction recommendations.

REFERENCES

Agricultural Stabilization Conservation Service, 1937, Aerial photography, Project AAL frames 2-64 through 2-73, 2-82 through 2-91, 3-18 through 3-28, and 3-35 through 3-45, dated 9-19-1937 and 9-21-1937, black and white, approximate scale 1:20,000.

Anderson, L.R., Keaton, J.R., Saarinen, T.F., and Wells, W.G., II, 1984, Utah landslides, debris flows, and floods of May and June 1983: Washington, D.C., National Research Council, Committee on Natural Disasters, National Academy Press, 96 p.

Ashland, F.A., 2003, Characteristics, causes, and implications of the 1998 Wasatch Front landslides, Utah: Utah Geological Survey Special Study 105, 49 p.

Ashland, F.X., Giraud, R.E., and McDonald, G.N., 2005, Groundwater-level fluctuations in Wasatch Front landslides and adjacent slopes, northern Utah: Utah Geological Survey Open-File Report 448, 22 p.

Ashland, F.X., Giraud, R.E., and McDonald, G.N., 2006, Slope-stability implications of groundwater-level fluctuations in Wasatch Front landslides and adjacent slopes, northern Utah, *in* 40th Symposium on Engineering Geology and Geotechnical Engineering, May 24–26, 2006: Logan, Utah, Utah State University, 12 p., compact disk.

Black, B.D., Solomon, B.J., and Harty, K.H., 1999, Geology and geologic hazards of Tooele Valley and the West Desert Hazardous Industry Area, Tooele County, Utah: Utah Geological Survey Special Study 96, 65 p., 6 plates.

Blake, T.F., Hollingsworth, R.A., and Stewart, J.P., editors, 2002, Recommended procedures for implementation of DMG Special Publication 117, Guidelines for analyzing and mitigating landslide hazards in California: Los Angeles, California, Southern California Earthquake Center at the University of Southern California, 125 p.

Cruden, D.M., and Varnes, D.J., 1996, Landslide types and processes, *in* Turner, A.K., and Schuster, R.L., editors, Landslides—investigation and mitigation: Washington, D.C., National Academy of Sciences, National Research Council, Transportation Research Board Special Report 247, p. 36–75.

Elliott, A.H., and Harty, K.M., 2010, Landslide maps of Utah: Utah Geological Survey Map 246DM, DVD, GIS data, 14 p., 46 plates, scale 1:100,000.

Giraud, R.E., and Shaw, L.M., 2007, Landslide susceptibility map of Utah: Utah Geological Survey Map 228DM, 11 p., 1 plate, scale 1:500,000.

Hylland, M.D., 1996, Guidelines for evaluating landslide hazards in Utah: Utah Geological Survey Circular 92, 16 p.

Hylland, M.D., Lowe, M., and Bishop, C.E., 1995, Engineering geologic map folio, western Wasatch County: Utah Geological Survey Open-File Report 319, 12 plates, scale 1:24,000.

Jibson, R.W., and Harp, E.L., 1995, The Springdale landslide, *in* Christenson G.E., editor, The September 2, 1992, M_L 5.8 St. George earthquake, Washington County, Utah: Utah Geological Survey Circular 88, p. 21–30.

Keefer, D.K., 1984, Landslides caused by earthquakes: Geological Society of America Bulletin, v. 95, p. 406–421.

Keller, E.A., and Blodgett, R.H., 2006, Natural hazards—Earth's processes as hazards, disasters, and catastrophes: Upper Saddle River, New Jersey, Pearson Prentice Hall, 395 p.

Neuendorf, K.K.E., Mehl, J.P., Jr., and Jackson, J.A., editors, 2005, Glossary of geology (fifth edition): Alexandria, Va., American Geological Institute, 800 p.

Salt Lake County, 2010, Salt Lake County Code of Ordinances (Chapter 19.72): Online, Bellevue, Washington, Matthew Bender & Company, Inc., http://library.municode.com/index.aspx?clientId=16602&stateId=44&stateName=Utah, accessed August 2010.

Schuster, R.L., 1996, Socioeconomic significance of landslides, *in* Turner A.K., and Schuster, R.L., editors, Landslides—investigation and mitigation: Washington, D.C., National Academy of Sciences, National Research Council, Transportation Research Board Special Report 247, p. 12–35.

Soil Conservation Service, 1940, Aerial photography, Project COI frames 1-18 through 1-25, dated 7-29-1940, black and white, approximate scale 1:20,000.

Soil Conservation Service, 1965, Aerial photography, Project AAL 2FF frames 7-17, 58-67, and 83-91, dated 7-26-1965, black and white, approximate scale 1:20,000.

Solomon, B.J., Biek, R.F., and Smith, T.W., 2007, Geologic map of the Magna quadrangle, Salt Lake County, Utah: Utah Geological Survey Map 216, scale 1:24,000.

Utah Automated Geographic Reference Center, State Geographic Information Database, 2006, 2 meter bare earth LiDAR: Utah Automated Geographic Reference Center: Online, http://gis.utah.gov/elevation-terrain-data/2-meter-lidar, accessed March 2009.

U.S. Geological Survey, 2009a, Landslide hazards program: Online, http://landslides.usgs.gov/, accessed August 2009.

U.S. Geological Survey, 2009b, FAQ's about landslides: Online, http://landslides.usgs.gov/learning/faq/, accessed November 2010.

Varnes, D.J., 1978, Slope, movement types and processes, *in* Schuster, R.L., and Krizek, R.J., editors, Landslides analysis and control: Washington, D.C., National Academy of Sciences, National Research Council, Transportation Research Board Special Report 176, p. 12–33.

Wieczorek, G.F., 1996, Landslide triggering mechanisms, *in* Turner A.K., and Schuster, R.L., editors, Landslides—investigation and mitigation: Washington, D.C., National Academy of Sciences, National Research Council, Transportation Research Board Special Report 247, p. 76–90.

Chapter 5
Rock-Fall Hazards

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Chapter 5: Rock-Fall Hazards

INTRODUCTION

Rock fall is a natural mass-wasting process that involves the dislodging and downslope movement of individual rocks and small rock masses (Varnes, 1978; Cruden and Varnes, 1996). Rock falls are a hazard because a large boulder traveling at high speed can cause significant damage. Rock falls can damage property, roadways, and vehicles, and pose a significant safety threat. Rock-fall hazards are found where a source exists above slopes steep enough to allow rapid downslope movement of dislodged rocks by falling, rolling, and bouncing. Most rock falls originate on slopes steeper than 35 degrees (Wieczorek and others, 1985; Keefer, 1993), although rock-fall hazards may be found on less steep slopes.

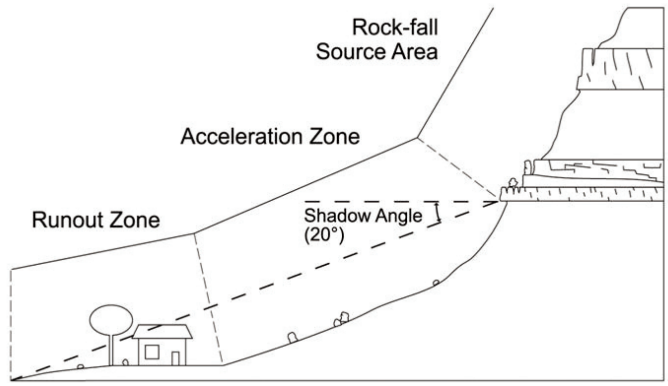

__Figure 5.1.__ Components of a characteristic rock-fall path profile.

Rock-fall-hazard potential is based on a number of factors including geology, topography, and climate. Rock-fall sources include bedrock outcrops or boulders on steep mountainsides or near the edges of escarpments such as ancient shorelines, bluffs, and terraces. Talus cones and scree-covered slopes are indicators of a high rock-fall hazard, although other areas are also vulnerable. Rock falls may be initiated by frost action, rainfall, weathering and erosion of the rock or surrounding material, and root growth, although in many cases a specific triggering event is not apparent. Rock falls may also be initiated by ground shaking, and are the most common earthquake-induced slope failures. Keefer (1984) indicates earthquakes as small as magnitude 4.0 can trigger rock falls. All nine historic Utah earthquakes of magnitude 5 or greater have caused rock falls. Slope modifications, such as cuts for roads and building pads or clearing of slope vegetation for development, can increase or create a local rock-fall hazard. Although not well documented, rock falls in Utah appear to occur more frequently during spring and summer months. This is likely due to spring temperature variations causing snow and ice to melt and re-freeze in rock fractures, to snowmelt, and to summer cloudburst storms (Castleton, 2009).

The rock-fall hazard map (plate 5) shows areas in the Magna quadrangle that may be susceptible to rock fall. Where no hazard is mapped, rock-fall hazards are either absent or are too localized to show on a 1:24,000-scale map. Each mapped category includes three components (figure 5.1): (1) a rock-fall source, in general defined by geologic units that exhibit relatively consistent patterns of rock-fall susceptibility throughout the study area, (2) an acceleration zone, where rock-fall fragments detached from the source and gain energy and momentum as they travel downslope—this zone often includes a talus slope, which becomes less apparent with decreasing relative hazard and is typically absent where the hazard is low, and (3) a runout zone or rock-fall shadow, including gentler slopes that may be covered discontinuously by scattered large boulders that have rolled or bounced beyond the base of the talus.

The extent of the rock-fall shadow is established using a shadow angle (figure 5.1), which is defined as the angle between a horizontal line and a line extending from the base of the rock-fall source to the outer margin of the runout zone (Evans and Hungr, 1993). We conservatively estimate the shadow angle to be 20 degrees, which is less than shadow angles observed by Evans and Hungr (1993) in three historical rock falls. This angle results in a shadow sufficiently wide to include the limits of rock-fall debris observed in northern Utah and the rock-fall runout distances estimated using the Colorado Rock-fall Simulation Program (CRSP) (Jones and others, 2000), a 2-dimensional computer model.

METHODS AND SOURCES OF DATA

To compile the rock-fall hazard map (plate 5) we used recent geologic mapping (Solomon and others, 2007); field observations; 1937, 1940, and 1965 U.S. Department of Agriculture aerial photographs (Agricultural Stabilization Conservation Service, 1937; Soil Conservation Service, 1940, 1965) (all 1:20,000 scale); and a hillshade and slope map derived from 2-meter bare earth Light Detection and Ranging (LiDAR) data (Utah Automated Geographic Reference Center, 2006).

We assigned a hazard designation of high, moderate, or low based on the following rock-fall-source parameters, of rock type, joints, fracture, orientation of bedding planes, and potential clast size, as described by geologic mapping (Solomon, 2007), as well as slope angle, acceleration zone and shadow angle. We evaluated slopes below rock-fall sources for slope angle; vegetation; and distribution, size range, amount of embedding, and weathering of rock-fall boulders.

USING THIS MAP

Plate 5 shows areas of relative rock-fall hazard in the Magna quadrangle where site-specific geotechnical/geologic-hazard investigations are recommended prior to construction. These investigations can resolve uncertainties inherent in generalized hazard mapping and help ensure safety by identifying the need for rock-fall-resistant design or mitigation. For most areas a site-specific investigation may only require a field geologic evaluation to determine if a rock-fall source is present. However, if a source is identified, additional work to adequately assess the hazard is needed. Rock-fall sources should be evaluated for the following parameters: rock type, joints, fractures, bedding planes, and potential clast size. Slopes below rock sources should be evaluated for slope angle; aspect; substrate; surface roughness; vegetation; and distribution, size range, amount of embedding, and weathering of rock-fall boulders. The need for site-specific geotechnical/geologic-hazard investigations depends upon the rock-fall-hazard potential and the nature of a structure's use and occupancy as defined by International Building Code (IBC) occupancy categories (International Code Council, 2009). Table 5.1 shows our recommended requirements for site-specific geotechnical/geologic-hazard investigations related to rock-fall hazards to protect life and safety. Evaluation of the runout zone below a source can be estimated using a simple 2-dimensional model such as CRSP.

MAP LIMITATIONS

Plate 5 is based on limited geologic and slope data, and aerial photography analysis. The quality of the map also depends on the quality of these data, which vary throughout the study area. The mapped boundaries between rock-fall-hazard categories are approximate and gradational. Small, localized areas of higher or lower rock-fall potential are likely to exist within any given map area, but their identification is precluded because of the effects of unconsidered factors, the generalized map scale, and the relatively sparse data. This map is not intended for use at scales other than 1:24,000, and is designed for use in general planning to indicate the need for site-specific geotechnical/geologic-hazard investigations. The categories do not consider hazards caused by cuts, fills, or other alterations to the natural terrain. The map is intended primarily for planning purposes and should not be used as a substitute

Table 5.1. *Recommended requirements for site-specific geotechnical/geologic-hazard investigations related to rock-fall hazards to protect life and safety.*

Hazard Potential	Classification of Buildings and Other Structures for Importance Factors[1]				
	I		II	III	IV
	One- and Two-Family Dwellings and Townhouses	All Other Buildings and Structures Except Those Listed in Groups II, III, and IV	Buildings and Other Structures that Represent a Substantial Hazard to Human Life in the Event of Failure	Buildings and Other Structures Designated as Essential Facilities	Buildings and Other Structures that Represent a Low Hazard to Human Life in the Event of Failure
High, Moderate	Yes	Yes	Yes	Yes	No[2]
Low	Yes	Yes	Yes	Yes	No[2]
None	No	No	No	No	No

[1]Occupancy category from International Building Code (2009).

[2]Property damage possible, but little threat to life safety.

for site-specific geotechnical/geologic-hazard investigations conducted by qualified professionals. Site-specific geotechnical/geologic-hazard investigations are required to produce more detailed rock-fall-hazard information.

HAZARD REDUCTION

Early recognition and avoidance of areas subject to rock fall are the most effective means of reducing risk. However, avoidance may not always be an option, especially for existing developments. Other techniques that may reduce potential rock-fall damage include, but are not limited to, rock scaling, rock stabilization, and/or engineered catchment structures. Rock scaling is the removal of rocks that are likely to fall from a slope. Rock-stabilization methods are physical means of reducing the hazard at the source using rock bolts, steel mesh, and/or shotcrete on susceptible outcrops. Engineered catchment structures such as berms, trenches, or benches can be placed below source areas, or at-risk structures themselves could be designed to stop, deflect, retard, or retain falling rocks.

The UGS recommends retaining a geotechnical firm familiar with rock-fall hazards early in the project design phase to conduct a site-specific investigation of the proposed site. If a rock-fall hazard is present, the geotechnical consultant should provide design, grading, scaling and/or construction recommendations as necessary to reduce the hazard.

REFERENCES

Agricultural Stabilization Conservation Service, 1937, Aerial photography, Project AAL frames 2-64 through 2-73, 2-82 through 2-91, 3-18 through 3-28, and 3-35 through 3-45, dated 9-19-1937 and 9-21-1937, black and white, approximate scale 1:20,000.

Castleton, J.J., 2009, Rock-fall hazards: Utah Geological Survey Public Information Series 94, 4 p.

Cruden, D.M., and Varnes, D.J., 1996, Landslide types and processes, *in* Turner A.K., and Schuster, R.L., editors, Landslides investigation and mitigation: Washington, D.C., National Academy of Sciences, National Research Council, Transportation Research Board Special Report 247, p. 36–75.

Evans, S.G., and Hungr, O., 1993, The assessment of rockfall hazard at the base of talus slopes: Canadian Geotechnical Journal, v. 30, p. 620–636.

International Code Council, 2009a, International building code: Country Club Hills, Illinois, International Code Council, 678 p.

Jones, C.L., Higgins, J.D., and Andrew, R.D., 2000, Colorado rockfall simulation program, version 4.0: Report prepared for the Colorado Department of Transportation, 127 p.

Keefer, D.K., 1984, Landslides caused by earthquakes: Geological Society of America Bulletin, v. 95, p. 406–421.

Keefer, D.K., 1993, The susceptibility of rock slopes to earthquake-induced failure: Bulletin of the Association of Engineering Geologists, v. 30, p. 353–361.

Soil Conservation Service, 1940, Aerial photography, Project COI frames 1-18 through 1-25, dated 7-29-1940, black and white, approximate scale 1:20,000.

Soil Conservation Service, 1965, Aerial photography, Project AAL 2FF frames 7-17, 58-67, and 83-91, dated 7-26-1965, black and white, approximate scale 1:20,000.

Solomon, B.J., Biek, R.F., and Smith, T.W., 2007, Geologic map of the Magna quadrangle, Salt Lake County, Utah: Utah Geological Survey Map 216, scale 1:24,000.

Utah Automated Geographic Reference Center State Geographic Information Database, 2006, 2 meter bare earth LiDAR: Utah Automated Geographic Reference Center, online, http://gis.utah.gov/elevation, accessed March 24, 2009.

Varnes, D.J., 1978, Slope movement types and processes, *in* Schuster, R.L., and Krizek, R.J., editors, Landslides analysis and control: Washington, D.C., National Academy of Sciences, National Research Council, Transportation Research Board Special Report 176, p. 12–33.

Wieczorek, G.F., Wilson, R.C., and Harp, E.L., 1985, Map showing slope stability during earthquakes in San Mateo County, California: U.S. Geological Survey Miscellaneous Investigations Series Map I-1257-E, scale 1:62,500.

Chapter 6
Indoor Radon Hazards

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Chapter 6: Indoor Radon Hazards

INTRODUCTION

Radon is an odorless, tasteless, and colorless radioactive gas that is highly mobile and can enter buildings through small foundation cracks and other openings such as utility pipes. The most common type of radon is naturally occurring and results from the radioactive decay of uranium, which is found in small concentrations in nearly all soil and rock. Although outdoor radon concentrations never reach dangerous levels because air movement and open space dissipate the gas, indoor radon concentrations may reach hazardous levels because of confinement and poor air circulation in buildings. Breathing any level of radon over time increases a person's risk of lung cancer, but long-term exposure to low radon levels is generally considered a small health risk. Smoking greatly increases the health risk due to radon, because radon decay products attach to smoke particles and are inhaled into the lungs, greatly increasing the risk of lung cancer. The U.S. Environmental Protection Agency (EPA, 2009) recommends that action be taken to reduce indoor radon levels exceeding 4 picocuries per liter of air (pCi/L), and cautions that indoor radon levels less that 4 pCi/L still pose a health risk, and in many cases can be reduced.

Indoor radon levels are affected by several geologic factors, including uranium content in soil and rock, soil permeability, and groundwater. Granite, metamorphic rocks, some volcanic rocks, shale, and soils derived from these rocks are generally associated with high uranium content contributing to high indoor radon levels. Elevated uranium concentrations are found in the Oquirrh Mountains in the western portion of the Magna quadrangle in the Permian Park City Formation and the Tertiary Salt Lake Formation; however, rocks associated with the Oquirrh Group are deficient in uranium (Black, 1996). The potential for increased indoor radon levels is greatest in areas underlain by the Park City and Salt Lake Formations, and in coarse-grained Quaternary alluvial-fan and Lake Bonneville deposits along the valley margins derived from them.

Soil permeability affects the mobility of radon from its source. If a radon source is present, the ability of radon to move upward through the soil into overlying buildings is facilitated by high soil permeability. Conversely, radon movement is impaired in soils with low permeability. Saturation of soil by shallow groundwater inhibits radon movement by dissolving radon in the water and reducing its ability to migrate upward through the soil (Black, 1996).

Along with geologic factors, a number of non-geologic factors also influence radon levels in a building. Although the influence of geologic factors can be estimated, the influence of non-geologic factors, such as occupant lifestyle and home construction methods, are highly variable. As a result, indoor radon levels fluctuate and can vary in structures built on the same geologic unit; therefore, the radon level must be measured in each building to determine if a problem exists. Testing is easy, inexpensive, and may often be conducted by the building occupant, but professional assistance is available (for more information visit http://radon.utah.gov).

The Utah Division of Radiation Control (UDRC) sampled indoor radon levels statewide (Sprinkel and Solomon, 1990; Solomon and others, 1993; Black, 1996), including areas in the Magna quadrangle. The UDRC found average indoor radon levels in the Magna quadrangle to be the same as the statewide average (2.7 pCi/L), but both are higher than average levels in the United States (1.3 pCi/L) (EPA, 1991). The elevated indoor radon levels and the geologic factors present that can produce high indoor radon levels indicate the need for testing in existing buildings and incorporating radon-resistant techniques in new construction.

METHODS AND SOURCES OF DATA

To map the indoor-radon-hazard potential (plate 6) we used four main sources of data to identify areas where underlying geologic conditions may contribute to elevated indoor radon levels. The four sources are: (1) *Radon-Hazard Potential of the Western Salt Lake Valley, Salt Lake County, Utah* (Black, 1996), (2) soil permeability data obtained from the U.S. Natural Resources Conservation Service (NRCS) *Soil Survey Geographic (SSURGO) Database for Salt Lake Valley Area Salt Lake County, Utah* (NRCS, 2006), (3) depth to groundwater mapping completed for this investigation, and (4) geologic mapping (Solomon and others, 2007).

To map the indoor radon hazard, we overlaid soil permeability data from the NRCS (2006), the radon-hazard potential of the western Salt Lake Valley (Black, 1996), groundwater data, and geologic units (Solomon and others, 2007), and assigned a hazard category as shown in table 6.1. We used the radon-hazard potential of the western Salt Lake Valley (Black, 1996), which covers most of the Magna quadrangle except for the western quarter, to obtain uranium characteristics for the Magna quadrangle. We classified soil and rock units into high, moderate, and low categories based on their potential to generate radon gas and the ability of the gas to migrate upward through the overlying soil and rock using the geologic factors uranium content, soil permeability, and depth to groundwater (after Black, 1996)

Table 6.1. Hazard-potential classifications based on geologic factors affecting the ability of radon gas to migrate upward through the overlaying soil and rock.

Geologic Factors	Radon Hazard Category[1]		
	Low	Moderate	High
Uranium (ppm)	< 2	2–3	> 3
Soil permeability	Impermeable (Hydraulic conductivity < 0.6 in/hr [< 4.23 µm/s])	Moderately permeable 0.6–6 in/hr (4.23 µm/s–42.34 µm/s)	Highly permeable > 6 in/hr (> 42.34 µm/s)
Depth to groundwater	< 10 ft (3 m)	10–30 ft (3 m–9 m)	> 30 ft (9 m)

[1]Classification based on methods from Black (1996)

Natural Resources Conservation Service Soil Data

The NRCS reports hydraulic conductivity (Ksat) values of saturated soil for their soil units based on testing performed at representative locations (NRCS, 2006). The NRCS assigned permeability classes to their soil units based on the hydraulic conductivity of the unit. Table 6.1 shows the relation of the permeability class to the hydraulic conductivity and the radon-hazard category. The hydraulic conductivity values of non-soil map units (water, borrow pits, and other artificial units as mapped by the NRCS) are reported as zero; however, they do not necessarily represent impermeable surfaces. Therefore, the hydraulic conductivity of adjacent units was assumed to apply to non-soil map units.

Groundwater

Groundwater is found in saturated zones beneath the land surface in soil and rock at various depths. Saturation of soil by shallow groundwater (less than 30 feet [10 m]) inhibits radon movement by dissolving radon in the water and reducing its ability to migrate upward through foundation soil (Black, 1996). Our groundwater mapping focuses on the principal aquifer where it is shallow and unconfined or artesian, and locally unconfined or perched aquifers 30 feet (9 m) or less below the ground surface. Water in the confined aquifer does not generally affect the movement of radon in foundation soils because it is deeper than 30 feet (9 m) (Black, 1996).

Geologic Mapping

We used recent geologic mapping (Solomon and others, 2007) to identify geologic units that may be high in uranium. Geologic mapping was relied on particularly outside of the areas covered by previous investigations (Black, 1996) where radiometric data were limited.

USING THIS MAP

The map of indoor-radon-hazard potential (plate 6) is intended to provide an estimate of the underlying geologic conditions that may contribute to the indoor radon hazard. The map does not characterize indoor radon levels because they are also affected by highly variable non-geologic factors. The map can be used to indicate the need for testing indoor radon levels; however, we recommend testing be completed in all existing structures.

MAP LIMITATIONS

Plate 6 is not intended to indicate absolute indoor radon levels in specific buildings. Although geologic factors contribute to elevated indoor-radon-hazard potential, other highly variable factors, such as building materials and foundation openings affect indoor radon levels; therefore, the indoor radon levels can vary greatly between structures located in the same hazard designation.

The hazard-potential categories on the map are approximate and mapped boundaries are gradational. Localized areas of higher or lower radon potential are likely to exist within any given map area, but their identification is precluded because of the generalized map scale, relatively sparse data, and non-geologic factors such as variability in building construction. The use of imported fill for foundation material can also affect radon potential in small areas, because the imported material may have different geologic characteristics than native soil. This map is not intended for use at scales other than 1:24,000, and is designed for use in general planning to indicate the need for site-specific testing of indoor radon level testing.

HAZARD REDUCTION

Techniques for reducing radon levels in existing buildings include: (1) preventing radon from entering the building, and (2) removing radon or its decay products from the building after entry. The specific technique chosen depends on the initial radon concentration, and building design and construction. Immediate actions to reduce indoor radon levels and/or associated health risks can be done quickly with a minimum of expense, but they are not long-term solutions. Immediate actions include discouraging smoking inside a home, spending less time in areas of high radon concentration, and improving ventilation by opening windows and using fans. Permanent actions to reduce indoor radon levels often require professional assistance to identify radon-entry routes and perform diagnostic testing to aid in the selection of the most effective radon-reducing technique (EPA, 2010; ASTM, 2009). If professional assistance is required to test for radon or reduce the indoor radon hazard, a qualified contractor should be selected. The EPA provides guidelines for choosing a contractor, and a listing of state radon offices, in *Consumer's Guide to Radon Reduction* (EPA, 2010).

New buildings may incorporate methods to restrict radon entry, and construction can also be incorporated during construction that facilitate radon removal after completion if prevention methods are inadequate. The EPA provides recommendations regarding construction techniques for new residential buildings (EPA, 1994; ASTM, 2008). The use of passive radon-control systems in areas of high radon-hazard potential, and the activation of those systems if necessitated by follow-up testing, is the best approach to achieve both significant radon-risk reduction and cost-effectiveness in new construction. A passive system includes construction techniques that create physical barriers to radon entry, reduce the forces that draw radon into a building, and facilitate post-construction radon removal if barrier techniques prove inadequate. Passive systems do not need the active participation of the occupant for operation or maintenance.

The International Residential Code (IRC), appendix F, Radon Control Methods, describes construction techniques that are consistent with the EPA recommendations (International Code Council, 2009). The adoption of IRC appendix F and implementation of its construction techniques are at the discretion of local jurisdictions. IRC figure AF101 assigns each of the counties in the United States to one of three zones based on radon potential. Salt Lake County is assigned to zone 2, indicating moderate potential for elevated levels of indoor radon, with an average expected short-term radon measurement from 2 to 4 pCi/L. The map of indoor-radon-hazard potential in the Magna quadrangle (plate 6) is more detailed and delineates areas of high, moderate, and low hazard potential, and should be used as a supplement to IRC figure AF101. The high hazard potential area is equivalent to zone 1 on IRC figure AF101, the moderate hazard potential area is equivalent to zone 2, and the low hazard potential area is equivalent to zone 3. The UGS recommends adoption of IRC appendix F and enforcement of its construction techniques in the high hazard potential areas, and appropriate disclosure of the potential hazard in moderate hazard potential areas, where radon-resistant construction can be used at the owners' discretion. Testing for indoor radon testing is important in all hazard categories.

REFERENCES

ASTM International, 2008, Standard practice for radon control options for the design and construction of new low-rise residential buildings: West Conshohocken, Pennsylvania, ASTM International, ASTM Standard E1465-08a, 38 p.

ASTM International, 2009, Standard practice for installing radon mitigation systems in existing low-rise residential buildings: West Conshohocken, Pennsylvania, ASTM International, ASTM Standard E2121-09, 13 p.

Black, B.D., 1996, Radon-hazard potential of western Salt Lake Valley, Salt Lake County, Utah: Utah Geological Survey Special Study 91, 28 p.

International Code Council, 2009, International residential code for one- and two-family dwellings: Country Club Hills, Illinois, International Code Council, 870 p.

Solomon, B.J., Biek, R.F., and Smith, T.W., 2007, Geologic map of the Magna quadrangle, Salt Lake County, Utah: Utah Geological Survey Map 216, scale 1:24,000.

Solomon, B.J., Black, B.D., Finerfrock, D.L., and Hultquist, J., 1993, Geologic mapping of radon-hazard potential in Utah, *in* The 1993 International Radon Conference, preprints: Denver, Colorado, American Association of Radon Scientists and Technologists, p. IVP-14 – IVP-28.

Sprinkel, D.A., and Solomon, B.J., 1990, Radon hazards in Utah: Utah Geological Survey and Mineral Survey Circular 81, 24 p.

U.S. Environmental Protection Agency, 1991, Indoor air quality, frequent questions: Online, http://www.epa.gov/iaq/index.html, accessed August 2009.

U.S. Environmental Protection Agency, 1994, Model standards and techniques for control of radon in new residential buildings: U.S. Environmental Protection Agency, Office of Air and Radiation, EPA 402-R-94-009, 15 p.

U.S. Environmental Protection Agency, 2009, A citizens guide to radon—the guide to protecting yourself and your family from radon: U.S. Environmental Protection Agency, U.S. Department of Health and Human Services, and U.S. Public Health Service, EPA 402/K-09/001, 15 p.

U.S. Environmental Protection Agency, 2010, Consumer's guide to radon reduction: U.S. Environmental Protection Agency, EPA 402/K-10/002, 12 p.

U.S. Natural Resources Conservation Service, 2006, Soil survey geographic (SSURGO) database for Salt Lake area, Salt Lake County, Utah: Online, http://soildatamart.nrcs.usda.gov/, accessed September 2008.

Chapter 7
Problem Soil and Rock

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Chapter 7: Problem Soil and Rock

INTRODUCTION

Soil and rock with characteristics that make them susceptible to volumetric change, collapse, subsidence, or other engineering-geologic problems are classified as problem soil and rock (Mulvey, 1992). Geologic parent material, climate, and depositional processes largely determine the type and extent of problem soil and rock. Because geologic materials and conditions in the Magna quadrangle are highly variable, various categories of problem soil and rock exist both locally and over broad areas. This study addresses three types of problem soil and rock found in the Magna quadrangle: (1) expansive soil and rock that are subject to shrinking and swelling when wetted or dried, (2) collapsible soil that is subject to collapse after wetting for the first time since deposition, and (3) shallow bedrock that impedes excavation and the proper functioning of soil-absorption wastewater-disposal systems.

The definitions of soil and rock used in this report generally conform to those in use by engineers and engineering geologists (Sowers and Sowers, 1970; U.S. Bureau of Reclamation, 1998, 2001). We define soil as any generally nonindurated accumulation of solid particles produced by the physical and/or chemical disintegration of bedrock, plus the gases or liquids between the particles, and which may or may not contain organic matter. Rock is defined as lithified or indurated crystalline or noncrystalline materials in which primary features of the rock mass, such as bedding, joints, or crystalline structure, are still recognizable. By this definition, rock weathered in place, even though it can be excavated without blasting or ripping, would still be considered rock and not a residual soil if primary features of the rock unit are still recognizable and can influence the engineering properties of the material.

COLLAPSIBLE SOIL SUSCEPTIBILITY

Description

Collapsible soils are relatively dry, low-density soils that decrease in volume or "collapse" when they become wet. Collapsible soils may have considerable strength and stiffness in their dry natural state, but can settle up to 10 percent of the susceptible deposit thickness when they become wet for the first time following deposition (Costa and Baker, 1981; Rollins and Rogers, 1994; Keaton, 2005), causing damage to property and structures. Collapsible soils are present in the Magna quadrangle and are typically geologically young materials, chiefly Holocene debris-flow sediments in alluvial fans in Pleistocene to Holocene lacustrine and colluvial deposits (plate 7).

Collapsible soils typically have a high void ratio, a corresponding low unit weight (< 80 to 90 lb/ft^3; Costa and Baker, 1981), and a relatively low moisture content (< 15%; Owens and Rollins, 1990), all characteristics that result from the initial rapid deposition and drying of the sediments. Intergranular bonds form between the larger grains (sand and gravel) of a collapsible deposit; these bonds develop through capillary tension or a binding agent such as silt, clay, or salt. Characteristically, collapsible soils consist of silty sands, sandy silts, and clayey sands (Rollins and Williams, 1991), although Rollins and others (1994) identified collapse-prone gravels containing as little as 5 to 20 percent fines at several locations in the southwestern United States. Later wetting of the soil results in a loss of capillary tension or the softening of the bonding material allowing the larger particles to slip past one another into a denser structure. Naturally occurring deep percolation of water into collapsible deposits is uncommon after deposition, due to the arid conditions in which the deposits typically form and the steep gradient of many alluvial fans. Therefore, soil collapse is often triggered by human activity such as irrigation, urbanization, or wastewater disposal.

Methods and Sources of Data

To create the collapsible-soil-susceptibility map (plate 7) we used two main sources of data to identify areas potentially affected by collapsible soils: a geotechnical database compiled for this report from geotechnical reports filed with local municipalities, and recent geologic mapping (Solomon and others, 2007). First, we evaluated test data from the geotechnical database; swell/collapse tests (SCT), dry density, and moisture tests were all used to determine collapse potential. Next, we incorporated geologic unit descriptions from recent geologic mapping (Solomon and others, 2007) with the geotechnical data to assign a susceptibility category to mapped geologic units. We classified unconsolidated geologic units into five categories based on their potential for collapse.

Geotechnical Database

For this report, we collected available geotechnical/geologic-hazard investigations in the files of local municipalities and compiled them into a database. SCT results are the most reliable indicator of soil-collapse potential, and were used as the principal indicator of soil-collapse potential. In the absence of SCT data, we used dry density and moisture test results as indicators of collapse potential. Collapsible soils typically have low density and low moisture content (Owens and Rollins, 1990). Our geotechnical database contains 137 SCT results for soil samples collected in the Magna quadrangle. Forty-three samples exhibited collapse, and seven had SCT values with ≥ 3 percent collapse, the level at which collapse becomes a significant engineering concern (Jennings and Knight, 1975).

Information in the geotechnical database represents site-specific geotechnical data available from local municipalities at the time of this study. Locally, conditions may differ from those shown on the map. Site-specific geotechnical/geologic-hazard investigations should be performed at all locations to resolve uncertainties inherent on the map.

Geologic Mapping

Collapse-susceptibility categories were assigned to geologic units mapped by Solomon and others (2007) based on geologic unit descriptions and geotechnical testing. Where geotechnical data provided evidence for high collapse susceptibility, as indicated by SCT results exhibiting collapse ≥ 3 percent, we delineated two susceptibility categories: highly collapsible soil, where SCT tests indicate collapse potential ≥ 5 percent, and collapsible soil A, where SCT tests indicate collapse potential > 3 percent and < 5 percent. For geologic units in which other geotechnical information (chiefly low density and moisture content) provided evidence for potentially collapsible soils, we delineated the collapsible soil B category using geologic contacts. Where geotechnical data were lacking, we assigned geologic units with a genesis and texture conducive to collapse to the category collapsible soil C. Finally, where older geologic units (Pleistocene) are mapped with no available geotechnical data, but with a genesis or texture permissive of collapse, we delineated the susceptibility category collapsible soil D. All susceptibility categories represent geologic units with a potential for collapse. Geologic units with SCT results indicating a demonstrated high percentage of collapse dictated that the geologic units containing the SCT test data are elevated above other similar geologic units lacking geotechnical test data. However, all mapped susceptibility categories may potentially exhibit a high percentage of collapse; therefore, site-specific investigations should be performed at all locations to resolve uncertainties inherent in the map.

Using This Map

Plate 7 shows the location of known and suspected collapsible soil conditions in the Magna quadrangle. The map is intended for general planning purposes to indicate where collapsible soils may exist. We recommend performing a site-specific geotechnical/geologic-hazard investigation for all development in the Magna quadrangle. Such investigations can resolve uncertainties inherent in generalized mapping and help ensure safety by identifying the need for special foundation designs, mitigation, and/or construction techniques. The presence and severity of collapsible soil along with other geologic hazards should be addressed in these investigations. If collapsible soil is present at a site, appropriate design and construction recommendations should be provided.

Map Limitations

The collapsible-soil-susceptibility map (plate 7) is based on limited geologic and geotechnical data. The quality of the map depends on the quality of these data, which vary throughout the study area. The mapped boundaries between susceptibility categories are approximate and subject to change with additional information. The collapse potential may be different than shown at any particular site due to variations within a geologic unit, gradational and approximate map-unit boundaries, and the generalized map scale. Small, localized areas of higher or lower collapsible-soil susceptibility may exist anywhere within the study area, but their identification is precluded by limitations of either data or map scale. This map is not intended for use at scales other than 1:24,000, and is designed for use in general planning to indicate the need for site-specific geotechnical/geologic-hazard investigations.

Hazard Reduction

Although potentially costly when not recognized and properly accommodated in project design and construction, problems associated with collapsible soil are rarely life threatening. Early recognition and avoidance are the most effective ways to mitigate potential problems associated with collapsible soil. However, because potentially collapsible soils are widespread in the Magna quadrangle, avoidance may not be a viable or cost-effective mitigation option.

In Utah, soil-test requirements are specified in the soil and foundations provisions of the International Building Code (IBC) chapter 18 (International Code Council, 2009a) and the foundations provisions of the International Residential Code (IRC) chapter 4, which are adopted statewide. The IBC contains requirements for soil investigations in areas where questionable soils (soil classification, strength, or compressibility) are present. The IRC (International Code Council, 2009b) states that the building official shall determine whether a soil test should be required to determine the soil's characteristics in areas likely to have expansive, compressible, shifting, or other unknown soil characteristics. Where the presence of collapsible soil is confirmed, possible mitigation techniques include soil removal and replacement with noncohesive, compacted backfill; use of special foundation designs, such as drilled pier and beam foundations or stiffened slab-on-grade construction; moisture barriers; foundation soil prewetting; and careful site landscape and drainage design to keep moisture away from buildings and collapse-prone soils (Keller and Blodgett, 2006).

EXPANSIVE SOIL AND ROCK

Description

Expansive soil and rock swell as they get wet, and shrink as they dry out. These changes in volume can cause cracked foundations and other structural damage to buildings and structures (figure 7.1), heaving and cracking of canals and road surfaces, and failure of wastewater-disposal systems. Expansive soil and rock contain a significant percentage of clay minerals that can absorb water directly into their crystal structure when wetted. At clay contents greater than approximately 12 to 15 percent, the expansive nature of the clay begins to dominate and the soil is subject to swell. Some sodium-montmorillonite clay can swell as much as 2000 percent upon wetting (Costa and Baker, 1981). The resulting expansion forces can be greater than 20,000 pounds per square foot (Shelton and Prouty, 1979), and can easily exceed the loads imposed by many structures. Expansive soils are chiefly derived from weathering of clay-bearing rock formations and may be residual (formed in place) or transported (usually a short distance) and deposited in a new location. The principal transporting mechanisms are water or wind, but soil creep and mass-wasting processes may play important roles locally.

Methods and Sources of Data

To map susceptibility to expansive soil and rock (plate 8), we used three main sources of data to identify areas potentially affected by expansive soil and rock: the U.S. Natural Resources Conservation Service (NRCS) *Soil Survey Geographic (SSURGO) Database for Salt Lake Valley Area, Salt Lake County, Utah* (NRCS, 2006), a geotechnical database compiled for this report from geotechnical reports filed with local municipalities, and recent geologic mapping (Solomon and others, 2007). We classified soil and rock units into three categories based on their potential for volumetric change: high, moderate, and low.

We examined the NRCS soil survey data and compared it to geotechnical testing data in our geotechnical database. Where discrepancies between the two existed, we modified susceptibility categories using geologic unit boundaries from Solomon and others (2007).

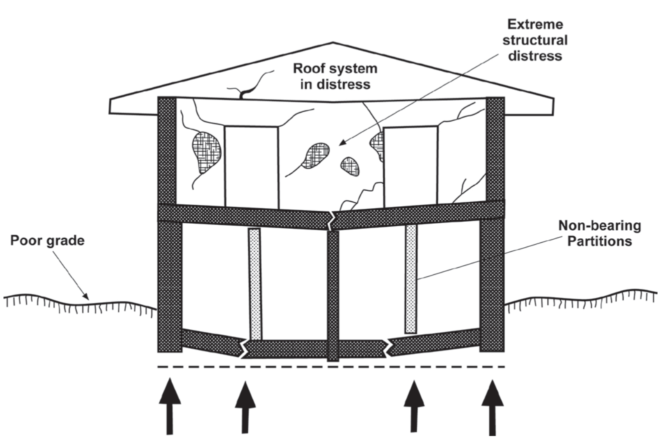

Figure 7.1. *Typical structural damage to a building from expansive soil (after Black and others, 1999).*

NRCS Soil Data

The initial step to create the susceptibility map (plate 8) was to look at the "Linear Extensibility" column of the "Physical Soil Properties" table in the NRCS soil survey of the Salt Lake area (2006). The NRCS defines linear extensibility as an expression of volume change that represents the "change in length of an unconfined clod as moisture content is decreased from a moist to a dry state" (NRCS, 2006). Table 7.1 shows the relation of the reported linear extensibility and the expansive-soil-susceptibility categories. We compared the ratings presented in the NRCS table with the laboratory test results in our geotechnical database. Correlations between the NRCS information and the geotechnical test data are generally good, but some discrepancies exist locally. Where geotechnical testing data showed elevated levels of swell potential, we used the geologic map data to modify the boundaries between susceptibility categories. This process is further described in the geotechnical database and geologic mapping sections below.

Geotechnical Database

For this report, we collected available geotechnical/geologic-hazard investigations in the files of local municipalities and compiled them into a database. For the map of expansive-soil-and-rock susceptibility (plate 8), we evaluated liquid limit (LL), plasticity index (PI), swell/collapse tests (SCT), and expansion index data reported in the geotechnical/geologic-hazard investigations. Table 7.2 shows the relation of these tests to the susceptibility categories on the map, and also reports the total number of each test included in the database. Swell/collapse tests are the most reliable indicator of swelling potential; we used them as the primary indicator of swell potential, and used LL and PI tests in the absence of SCT data. The ranges of LL and PI overlap between susceptibility categories (table 7.2). Therefore, we compared them for each boring, and we report the worst-case scenario for each boring (e.g., if the reported values fell into both moderate and high susceptibility categories, we report a high susceptibility).

Chen (1988) recognized that while PI is an indicator of expansive potential, other factors also exert an influence, and therefore reported a range of PI values that categorize a soil's capacity to shrink or swell. Chen (1988) presented a correlation between swell potential and PI (table 7.2) that illustrates the use of PI as an indicator of swelling potential. The use of PI values can assist in selecting samples for swell/collapse testing. Chen (1988) placed the lower bound of soils with high swelling potential at a PI of 20, but also included soils with a PI between 20 and 35 in the moderate category. Therefore, using a PI between 20 and 35 from a site-specific geotechnical investigation as an indicator of high swell potential is conservative and may overestimate the potential for high swell values at the site. In contrast, the IRC and the IBC (International Code Council, 2009a and 2009b), which use PI as one of four criteria to determine if soils are considered

Table 7.1. Relationship of the expansive-soil-and-rock-susceptibility categories and the NRCS reported linear extensibility.

Category	Linear Extensibility	Description	Location (as reported by the NRCS)
High	> 6%	Soils/rocks with a high potential for volumetric change. These soils/rocks are generally clay rich.	Common on the nearly flat valley floor which is underlain by Lake Bonneville clay either at the ground surface or at shallow depths beneath younger surficial deposits associated with Great Salt Lake. Also found in the Oquirrh Mountains in tuffaceous deposits.
Moderate	3–6%	Soils/rocks with a moderate potential for volumetric change. These soils/rocks are also clay rich, but contain significant intervals of silt and sand interbeds.	Common below the Provo shoreline where deposits are underlain by interbedded Lake Bonneville gravel, sand, silt and clay. May locally include thick deposits of lacustrine clay. Also found in the Oquirrh Mountains in deposits associated with the weathering of limestone and shale.
Low	< 3%	Soils/rocks with a low potential for volumetric change. Predominantly sand and gravel on the valley margins.	Common above the Provo shoreline where deposits are dominated by sand, gravel, and bedrock.

expansive, include soils having a PI of 15 or greater in the expansive soil category. In general, PI values 20 can serve as a rough indicator of high swell potential in the Magna quadrangle, and can be used to select samples for more extensive swell/collapse testing.

The Unified Soil Classification System (USCS) uses LL data when classifying fine-grained soils. The USCS classifies soils with an LL greater than 50 as highly plastic (capable of being permanently deformed without breaking); such soils typically contain expansive ("fat") clays. The USCS classifies fine-grained soils, including soils that are not expansive ("lean"), with an LL less than 50 as having low or medium plasticity.

Information in the geotechnical database represents site-specific geotechnical data available from local municipalities at the time of this study. However, because we only collected geotechnical data from local municipalities, the database does not represent all potentially available data for the study area. Although the information in the database is generally spread throughout the Magna quadrangle, there are many locations where no data were available. Locally, conditions may differ from those shown on the map. Site-specific geotechnical/geologic-hazard investigations should be performed at all locations to resolve uncertainties inherent on the map.

Geologic Mapping

Where geotechnical data provided evidence for expansive soils, we modified the high-susceptibility boundaries using geologic contacts as mapped by Solomon and others (2007). We identified six Quaternary units (Qldy, Qly, Qlay, Qlmy, Qll, and Qlmbp) and one bedrock unit (Tsl) as consisting in part of expansive clay minerals by examining geologic unit descriptions and geotechnical testing data in the units. We classified them as having moderate or high swell potential depending on geotechnical testing data from the unit and its NRCS classification. The Quaternary units are fine-grained deposits associated with Great Salt Lake, the ancestral Jordan River delta, or Lake Bonneville. The bedrock unit, the Jordan Narrows unit of the Salt Lake Formation, includes tuff and tuffaceous rocks consisting of fine-grained volcanic material that contains abundant expansive clay minerals. This bedrock unit weathers to clay-rich soils that are capable of significant expansion and contraction when wetted and dried. In addition, we included landslides mapped in this bedrock unit in the high susceptibility category because they also include fine-grained, clay-rich material weathered from the Jordan Narrows unit of the Salt Lake Formation.

We also modified moderate-susceptibility boundaries using geologic contacts as mapped by Solomon and others (2007) where geotechnical test data indicated a moderate potential for shrink/swell (table 7.2). These geologic units include interbedded Lake Bonneville gravel and sand deposits (Qlsbp, Qlsp, Qlgbp, and Qlgp) below the Provo shoreline with thick clay beds (as shown in boring logs in the geotechnical database).

Low-susceptibility boundaries were generally not modified from the NRCS data. The only exception is in areas where modified high- or moderate-susceptibility boundaries overlapped areas mapped by the NRCS of low susceptibility. Where this occurred, we modified the low-susceptibility boundaries to reflect the changes made to the high- and moderate-susceptibility boundaries.

We included geologic units with elevated SCT results in the high-susceptibility category. We mapped other areas of the same or similar geologic units (including areas lacking geotechnical test data), based on NRCS linear extensibility. However, individual sites within all mapped susceptibility categories (high, moderate, low) may exhibit a high percentage of swell; therefore, site-specific geotechnical/geologic-hazard investigations should be performed at all locations to resolve uncertainties inherent on the map.

Using This Map

Plate 8 shows areas of known or suspected susceptibility to expansive soil and rock in the Magna quadrangle. The map is intended for general planning purposes to indicate where expansive soil and rock may exist and site-specific geotechnical/geologic-hazard investigations are required. We recommend performing a site-specific geotechnical/geologic-hazards investigation for all development in the Magna quadrangle. Site-specific investigations can resolve uncertainties inherent in generalized mapping and help ensure safety by identifying the need for special foundation designs or mitigation techniques. The presence and severity of expansive soil and rock along with other geologic hazards should be addressed in these investigations. If expansive soil or rock is present at a site, appropriate design and/or construction recommendations should be provided.

Map Limitations

The map is based on limited geologic and geotechnical data, the quality of which vary throughout the study area. The mapped boundaries between susceptibility categories are approximate and subject to change with additional information. The hazard from expansive soil and rock at any particular site may be different than shown because of geological variations within a map unit, gradational and approximate map-unit boundaries, and the generalized map scale. Small, localized areas of higher or lower expansive-soil-and-rock susceptibility may exist anywhere within the study area, but their identification is precluded due to limitations of either data or map scale. This map is not intended for use at scales other than 1:24,000, and is designed for use in general planning to indicate the need for site-specific geotechnical/geologic-hazard investigations. Comprehensive site-specific geotechnical/geologic-hazard investigations are required to produce more detailed information on expansive-soil-and-rock susceptibility.

Hazard Reduction

Although potentially costly when not recognized and properly accommodated in project design and construction, problems associated with expansive soil and rock are rarely life threatening. Early recognition and avoidance are the most effective ways to mitigate potential problems associated with expansive soil and rock. However, because expansive soil and rock are widespread in the Magna quadrangle, avoidance may not be a viable or cost-effective mitigation option.

Table 7.2. *Correlation between geotechnical tests of soils in the Magna quadrangle, expansive-soil-and-rock susceptibility, and the total number of tests reported for each test and category.*

Test	Low		Moderate		High	
	Value	Total in Database	Value	Total in Database	Value	Total in Database
SCT	0–2%	133 (includes 43 with only collapse reported)	2–3%	2	≥ 3%	2
LL	0–30	39	20–50	63	≥ 45	13
PI[1]	0–15	39	10–35	63	≥ 20	13
Expansion Index[2]	0–50	2	51–90	0	> 91	0

[1]Modified from Chen (1988).

[2]Modified from Nelson and Miller (1992).

In Utah, soil test requirements are specified in the soil and foundations provisions of IBC Chapter 18 (International Code Council, 2009a) and the foundations provisions of the IRC (International Code Council, 2009b) Chapter 4, which are adopted statewide. Section 1803.5.3 of the IBC and IRC Section R401.4 contain requirements for soil investigations in areas where expansive soil may be present. Where the presence of expansive soil or rock is confirmed, possible mitigation techniques include soil or rock removal and replacement with noncohesive, compacted backfill; use of special foundation designs such as drilled pier and beam foundations or stiffened slab-on-grade construction; moisture barriers; foundation soil prewetting; chemical stabilization of expansive clays (Nelson and Miller, 1992); and careful site landscape and drainage design to keep moisture away from buildings and expansive soils (Keller and Blodgett, 2006).

SHALLOW BEDROCK

Description

Unweathered bedrock formations that are not significantly fractured provide incompressible foundations with high shear strengths, making mechanical compaction and excavation of these materials generally ineffective and unnecessary (Christenson and Deen, 1983). The principal problem related to these materials is difficulty of excavation, particularly in highly resistant, unweathered bedrock units. Shallow bedrock makes excavations for basements, foundations, underground utilities, and road cuts difficult.

Resistant bedrock that crops out at or near the ground surface is readily apparent in the Oquirrh Mountains in the western portion of the Magna quadrangle. Less obvious are areas of shallow bedrock within the valley, commonly consisting of softer rocks of the Tertiary Salt Lake Formation overlain by a thin cover of unconsolidated Lake Bonneville and younger alluvial deposits.

Methods and Sources of Data

To compile the shallow-bedrock map (plate 9), we used four sources of data to identify areas of surficial and shallow bedrock: (1) recent geologic mapping (Solomon and others, 2007), (2) the U.S. Natural Resources Conservation Service (NRCS) *Soil Survey Geographic (SSURGO) Database for Salt Lake Valley Area, Salt Lake County, Utah* (NRCS, 2006), (3) a geotechnical database compiled for this report from geotechnical reports filed with local municipalities, and (4) the Utah Division of Water Rights well information program WELLVIEW (Utah Division of Water Rights, 2009).

Geologic Mapping

We used recent geologic mapping (Solomon and others, 2007) to identify areas where bedrock crops out at the ground surface. We qualitatively classified bedrock units as either "hard" or "soft." "Hard" bedrock units include the Permian Park City and Phosphoria Formations and the Permian to Pennsylvanian Kessler Canyon Formation (map symbols Ppc, Pppk, Ppok in Solomon and others [2007]), which consist of limestone, dolomite, quartzite, and sandstone. Only one "soft" bedrock unit, the tuffaceous Jordan Narrows unit of the Tertiary Salt Lake Formation (Tsl) is mapped in the Magna quadrangle.

Solomon and others (2007) mapped two geologic units (Qlgb/Ppc, Qlgb/Ppok) consisting of a thin veneer (less than 10 feet [3 meters]) of Lake Bonneville sediments partially concealing the Park City and Kessler Canyon Formations that we included in the "buried" shallow-bedrock category.

NRCS Soil Data

After identifying areas where bedrock crops out at the surface, we used the "Restrictive Layer" column of the "Soil Features" table in the NRCS soil survey of the Salt Lake Valley area (2006), to identify areas of potentially shallow bedrock. The "Restrictive Layer" column identifies areas where "lithic bedrock" was found less than 200 cm (6.5 ft) below the surface. Other restrictive layers (such as duripan and petrocalcic layers) are also identified in the "Soil Features" table, but were not considered in this map because they are likely related to cemented Lake Bonneville sediments and not shallow bedrock. However, areas of duripan or petrocalcic layers can still pose difficulty in excavations or subsurface investigations.

Geotechnical Database

For this report, we collected available geotechnical/geologic-hazard investigations in the files of local municipalities and compiled them into a database. For the shallow-bedrock map (plate 9), we used geotechnical borehole logs in the database to help identify areas with shallow bedrock. These borehole logs were compared with the geologic map, and NRCS soils information. Correlations between the geotechnical borehole logs, geologic mapping, and NRCS information are generally good, but some local discrepancies exist.

Information in the geotechnical database represents site-specific geotechnical data available from local municipalities at the time of this study. However, because we only collected geotechnical data from local governments, the geotechnical database does not represent all potentially available data for the study area. Although the information in the geotechnical database is distributed throughout the Magna quadrangle, there are many locations where no data were available. Locally, conditions may differ from those shown on the map. Site-specific geotechnical/geologic-hazard investigations should be performed at all locations to resolve uncertainties inherent on the map.

Utah Division of Water Rights Well Information Program

The Utah Division of Water Rights well information program WELLVIEW (Utah Division of Water Rights, 2009) includes well log records from 1991 to the present. These well logs include a lithological description of materials encountered while drilling. We compared the data from the well logs to geologic mapping, NRCS soil mapping, and geotechnical testing information to confirm the existence of shallow bedrock where it was identified by NRCS soil mapping and to identify other potential areas of shallow bedrock. Although several well logs identified potential shallow bedrock areas, other well logs in the same areas do not show shallow bedrock; either these are localized areas of shallow bedrock too small to show at 1:24,000-scale, or they were misidentified in the original well logs.

Using This Map

The shallow-bedrock map (plate 9) shows the locations where bedrock crops out at the ground surface or is present in the shallow subsurface in the Magna quadrangle. The map is intended for general planning purposes to indicate where adverse bedrock conditions may exist and site-specific geotechnical/geologic-hazard investigations may be required. We recommend performing site-specific geotechnical/geologic-hazard investigations for all development in the Magna quadrangle. Site-specific geotechnical/geologic-hazard investigations can resolve uncertainties inherent in generalized mapping and help ensure safety by identifying the need for special foundation designs or mitigation, and/or construction techniques. The presence and severity of bedrock conditions, along with other geologic hazards, should be addressed in these investigations. If shallow bedrock is present at a site, appropriate design and/or construction recommendations should be provided. Where onsite wastewater-disposal systems are planned, system installation must meet the requirements of Utah Department of Environmental Quality Rule R317-4-5, Soil and Groundwater Requirements (Utah Department of Environmental Quality, 2010), which prohibits installation of onsite wastewater-disposal systems in bedrock.

Map Limitations

The shallow-bedrock map is based on limited geologic and geotechnical data. The quality of the map depends on the quality of these data, which vary throughout the study area. The mapped boundaries between categories are approximate and subject to change with additional information. The shallow bedrock at any particular site may be different than shown because of geological variations within a map unit, gradational and approximate map-unit boundaries, and the generalized map scale. Therefore, small areas of shallow bedrock may exist throughout the study area, but their identification is precluded because of limitations of map scale. This map is not intended for use at scales other than 1:24,000, and is designed for use in general planning to indicate the need for site-specific geotechnical/geologic-hazard investigations, which are required to produce more detailed shallow-bedrock information.

Hazard Reduction

Although potentially costly when not recognized and properly accommodated in project design and construction, problems associated with shallow bedrock are not life threatening. Early recognition and avoidance are the most effective ways to reduce potential problems associated with shallow bedrock. If avoidance is not possible, pre-construction planning and design based on thorough, site-specific geotechnical/geologic-hazard investigations of construction sites can reduce potential problems. Where shallow bedrock is present, blasting may be required to excavate, and a sewer system may be required for waste-water disposal.

REFERENCES

Black, B.D., Solomon, B.J., and Harty, K.M., 1999, Geology and geologic hazards of Tooele Valley and the West Desert Hazardous Industry Area, Tooele County, Utah: Utah Geological Survey Special Study 96, 65 p., 6 plates.

Chen, F.H., 1988, Foundations on expansive soils: Amsterdam, the Netherlands, Elsevier, 463 p.

Christenson, G.E., and Deen, R.D., 1983, Engineering geology of the St. George area, Washington County, Utah: Utah Geological and Mineral Survey Special Study 58, 32 p., 2 plates in pocket.

Costa, J.E., and Baker, V.R., 1981, Surficial geology, building with the earth: New York, John Wiley & Sons, 498 p.

International Code Council, 2009a, International building code: Country Club Hills, Illinois, 678 p.

International Code Council, 2009b, International residential code for one- and two-family dwellings: Country Club Hills, Illinois, 870 p.

Jennings, J.F., and Knight, K., 1975, A guide to construction on or with materials exhibiting additional settlement due to “collapse” of grain structure: Sixth Regional Conference for Africa on Soil Mechanics and Foundation Engineering, Durban, South Africa, p. 99–104.

Keaton, J.R., 2005, Considering collapsible soil hazards for siting and design of natural gas pipelines [abs]: Geological Society of America Abstracts with Programs, v. 37, no. 7, p. 328.

Keller, E.A., and Blodgett, R.H., 2006, Natural hazards—Earth’s processes as hazards, disasters, and catastrophes: Upper Saddle River, New Jersey, Pearson Prentice Hall, 395 p.

Mulvey, W.E., 1992, Soil and rock causing engineering geologic problems in Utah: Utah Geological Survey Special Study 80, 23 p., 2 plates, scale 1:500,000.

Nelson, J.D., and Miller, D.J., 1992, Expansive soils, problems and practice in foundation and pavement engineering: New York, John Wiley & Sons, 259 p.

Owens, R.L., and Rollins, K.M., 1990, Collapsible soil hazard map for the southern Wasatch Front, Utah: Utah Geological and Mineral Survey Miscellaneous Publication 90-1, 34 p.

Rollins, K.M., and Rogers, G.W., 1994, Mitigation measures for small structures on collapsible alluvial soils: Journal of Geotechnical Engineering, v. 120, no. 9, p. 1533–1553.

Rollins, K.M., and Williams, T., 1991, Collapsible soil hazard mapping for Cedar City, Utah, *in* McCalpin, J.P., editor, Engineering geology & geotechnical engineering no. 27: Pocatello, Idaho, Idaho State University, p. 31-1 to 31-16.

Rollins, K.M., Rollins, R.L., Smith, T.D., and Beckwith, G.H., 1994, Identification and characterization of collapsible gravels: Journal of Geotechnical Engineering, v. 120, no. 3, p. 528–542.

Shelton, D.C., and Prouty, D., 1979, Nature's building codes: Colorado Geological Survey Special Publication 12, p. 37–40.

Solomon, B.J., Biek, R.F., and Smith, T.W., 2007, Geologic map of the Magna Quadrangle, Salt Lake County, Utah: Utah Geological Survey Map 216, scale 1:24,000.

Sowers, G.B., and Sowers, G.F., 1970, Introductory soil mechanics and foundations (3rd edition): New York City, The MacMillan Company, 556 p.

U.S. Bureau of Reclamation, 1998, Earth manual—Part 1 (3rd edition): Denver, Colorado, U.S. Bureau of Reclamation, Earth Sciences and Research Laboratory, 311 p.

U.S. Bureau of Reclamation, 2001, Engineering geology field manual—Volume 1 (2nd edition): Washington, D.C., U.S. Bureau of Reclamation, 432 p.

U.S. Natural Resources Conservation Service, 2006, Soil survey geographic (SSURGO) database for Salt Lake area, Salt Lake County, Utah: Online, http://soildatamart.nrcs.usda.gov/, accessed December 2008.

Utah Department of Environmental Quality, 2010, Onsite wastewater systems rule, R317-4-5 soil and groundwater requirements: Utah Administrative Code, Online, http://www.rules.utah.gov/publicat/code/r317/r317-004.htm#T5, accessed August 2010.

Utah Division of Water Rights, 2009, Points of diversion database (well information program "WELLVIEW"): Online, http://www.waterrights.utah.gov/gisinfo.wrcover.asp (shapefile) and http://www.waterrights.utah.gov/cgi-bin/wellview.exe?Startup (WELLVIEW program), accessed September 2009.

Chapter 8
Shallow Groundwater

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Chapter 8: Shallow Groundwater

INTRODUCTION

Groundwater is found in saturated zones beneath the land surface in soil and rock at various depths. Shallow groundwater levels are typically dynamic and fluctuate in response to a variety of conditions; groundwater levels may rise or fall in response to long-term climatic change, seasonal variations in precipitation, irrigation, and to the effects of urban development. Most development-related groundwater problems occur when water is within 10 feet (3 m) of the ground surface. Shallow groundwater can flood basements and other underground facilities, damage buried utility lines, and destabilize excavations. Groundwater inundation of landfills, waste dumps, and septic-tank systems can impair the performance of those facilities and lead to groundwater contamination. Because of its ability to change the physical and chemical nature of rock and soil, groundwater can also activate expansive and collapsible soils, and is a major factor in slope instability (Ashland and others, 2005, 2006). During earthquakes, groundwater within 50 feet (15 m) of the ground surface can cause soil liquefaction in sandy soils.

Groundwater may exist under either unconfined (water table) or confined (artesian/pressurized) conditions, in regional aquifers, or as local perched zones. In the Salt Lake Valley, groundwater exists in a deep unconfined aquifer near the mountain fronts, a deep confined aquifer extending into the center of the valley, a shallow unconfined aquifer, and locally unconfined or perched aquifers (Hely and others, 1971). The geology of the Salt Lake Valley, including the northwest portion where the Magna quadrangle is located, is highly variable. Interbedded clay, silt, sand, and gravel deposited during the Bonneville Lake cycle (Solomon and others, 2007) give rise to a complex groundwater system. Lake Bonneville deposits commonly consist of both low permeability silt and clay and highly permeable coarse sand and gravel, so that a single geologic unit may contain both locally perched groundwater and the sediments that isolate it from the deeper aquifers. The deep unconfined aquifer is composed of coarse-grained, unconsolidated sediments deposited during the Quaternary and possibly late Tertiary periods. The deep confined aquifer consists of interbedded deposits of clay, silt, sand, and gravel of Quaternary and possibly Tertiary age overlain by discontinuous layers of silt and clay of late Quaternary age. The deep unconfined and confined aquifers are commonly grouped together and called the principal aquifer (Thiros, 1995). Groundwater from the principal aquifer can be forced upward by artesian pressure to the ground surface where it is discharged through springs and seeps. The shallow unconfined aquifer is typically present where confining layers overlie the principal aquifer (Thiros, 1995). Perched groundwater develops where water from precipitation, irrigation, or urban runoff percolates through thin, permeable, unconsolidated surface deposits and collects above less permeable underlying clay layers.

This study focuses on the principal aquifer where it is shallow, and on locally unconfined or perched aquifers 50 feet (15 m) or less below the ground surface occurring in either the principal aquifer or locally unconfined or perched aquifers. However, the shallow-groundwater-potential map (plate 10) does not differentiate between aquifers and is not intended to model a deeper regional aquifer; instead it indicates the potential for shallow groundwater resulting from soil drainage capacity, geology, and hydrology.

A semi-arid climate characterizes the Salt Lake Valley. Average annual precipitation for Salt Lake City is 15.27 inches (38.79 cm) (National Weather Service Forecast Office, 2009). Most precipitation for the region accumulates as snow in the mountains during fall, winter, and spring. Runoff, mostly from melting snow, is usually greatest during May and June and contributes to groundwater recharge. Groundwater associated with the principal aquifer is shallow (less than 10 feet [3 m] below the ground surface) in the northern portion of the Magna quadrangle, and generally increases in depth to the south-southwest where shallow groundwater is more likely artesian or perched. Recent geotechnical/geologic-hazard investigations in West Valley City indicate shallow groundwater extends to an area from approximately 3500 South to 5400 South and between 4800 West and 6400 West. Surficial deposits there are highly variable and range from impermeable to moderately permeable lacustrine silt, sand, and gravel. Groundwater data in the quadrangle were limited in areas outside of the recent development; therefore, perched water may extend outside of the mapped zone of shallow groundwater. Perched groundwater and seasonally shallow groundwater may locally contribute to development problems even in areas without persistent shallow groundwater.

METHODS AND SOURCES OF DATA

To map shallow-groundwater potential we used six main sources of data: (1) the U.S. Natural Resources Conservation Service (NRCS) *Soil Survey Geographic (SSURGO) Database for Salt Lake Valley Area, Salt Lake County, Utah* (NRCS, 2006), (2) a geotechnical database compiled for this report, (3) previous groundwater investigations, (4) water-well driller's logs on file with the Utah Division of Water Rights, (5) private industry water well data, and (6) recent

Table 8.1. Shallow-groundwater-potential categories.

Groundwater Category	Definition
SGW_1	Soils mapped by the (NRCS) as naturally wet (depth to groundwater < 60 inches [152 cm]), poorly drained or frequently irrigated, and where water-well or geotechnical data indicate a significant area of permanent shallow groundwater (< 10 feet [3 m]). Following development, landscape irrigation and other sources of urban runoff may cause groundwater levels to rise even higher in these areas.
SGW_2	Soils mapped by the NRCS as poorly drained, generally fine-grained soils that may develop shallow groundwater locally when rates of water application exceed the soil's drainage capacity. Subsurface drains are frequently required to prevent these soils from becoming saturated. Because these soils naturally drain slowly, they may remain wet for most of the year, even though water is applied only during the growing season. Permanent shallow groundwater is possible following urbanization. Groundwater is likely ≤50 feet (15 m) below the ground surface.
SGW_3	Soils mapped by the NRCS as moderately to freely draining soils that are commonly irrigated for agricultural purposes. Groundwater is likely ≥50 feet (15 m) below the ground surface; however, where intense water application occurs, these soils may develop seasonally high groundwater, but typically drain quickly once water application stops or is reduced below the soil's drainage capacity. Seasonal or transient shallow groundwater is possible especially following development; landscape irrigation and other sources of urban runoff may cause groundwater levels to rise even higher in these areas.

geologic mapping (Solomon and others, 2007). The shallow-groundwater-potential map (plate 10) is not intended to provide numerical depths to groundwater but rather to indicate where shallow groundwater may affect development and contribute to other geologic hazards. We classified three categories of shallow-groundwater potential (table 8.1) to identify soil and rock units that are either naturally wet or have the potential to develop wet conditions. The categories define the conditions under which shallow groundwater may occur, but the categories do not represent relative severity rankings, as is the case on most of the hazard maps in this study.

We obtained groundwater-level data from previous geotechnical/geologic-hazard investigations conducted within the Magna quadrangle and incorporated them into our database. The NRCS mapped the occurrence of wet or potentially wet soil conditions. Wet conditions are defined by the NRCS as soils in which depth to groundwater < 60 inches (152 cm), and potentially wet soil conditions are defined by the NRCS as poorly drained, fine-grained soils that may develop shallow groundwater locally when rates of water application exceed the soil's drainage capacity. This data provided the base for our shallow-groundwater-potential map. We modified NRCS units where depth to groundwater was observed to be shallow (≤ 10 feet [3m]) in geotechnical borings and water well logs. To account for temporal and seasonal fluctuations in groundwater, we used the most conservative (shallow) depth to groundwater reported in an area. In addition, we made minor, local modifications to the NRCS soil data in areas with geotechnical data by considering the distribution of unconsolidated geological deposits typically associated with shallow groundwater (Solomon and others, 2007).

USING THIS MAP

Plate 10 shows the location of known and possible areas of shallow groundwater in the Magna quadrangle. The map is intended for general planning purposes to indicate where shallow groundwater may be present and where site-specific geotechnical/geologic-hazard investigations may be required. The UGS recommends a site-specific geotechnical/geologic-hazard investigation for development at all locations in the Magna quadrangle. Such investigations can resolve uncertainties inherent in generalized hazard mapping and help ensure safety by identifying the need for special foundation designs or mitigation and/or construction techniques. Site-specific investigations are particularly important for areas within the Magna quadrangle because local areas of shallow perched groundwater too small to show at the map scale (1:24,000) may be present anywhere within the quadrangle. These investigations may require installing and monitoring observation wells through more than one season, and/or examining sediments exposed in test pits for evidence of seasonal groundwater fluctuations.

MAP LIMITATIONS

The map of shallow-groundwater potential (plate 10) is based on limited geologic, geotechnical, and hydrological data. The map depends on the quality of those data, which vary throughout the study area. Therefore, map-unit boundaries are approximate and subject to change with additional information. Shallow-groundwater conditions at any particular location may be different than shown because of geological or hydrological variations within a map unit, gradational and approximate map-unit boundaries, and the generalized map scale. Local areas of shallow, perched groundwater may exist anywhere within the map area, but their identification is precluded because of data limitations and map scale. Seasonal and long-term fluctuations in weather patterns and changes in land use also may affect the depth to groundwater at a site. This map is not intended for use at scales other than 1:24,000, it is designed for use in general planning to indicate the need for site-specific geotechnical/geologic-hazard investigations. Comprehensive site-specific geotechnical/geologic-hazard investigations are required to produce more detailed shallow-groundwater information. If shallow groundwater is present, the site-specific investigation should provide appropriate design and/or construction recommendations.

HAZARD REDUCTION

Although potentially costly when not recognized and properly accommodated in project design, hazards due to shallow groundwater are not life threatening. International Building Code section 1805 (International Code Council, 2009a) and International Residential Code section R406 (International Code Council, 2009b) contain damp-proofing and waterproofing requirements for structures built in wet areas. Slab-on-grade construction is common in shallow-groundwater areas, as is placing fill on a site to raise building elevations where seasonal fluctuations in groundwater may bring water very near or to the ground surface. Other possible groundwater mitigation techniques include installing well-point systems, sump pumps, horizontal drains, and vertical sand drains, or creating a groundwater barrier using sheet piling, cutoff walls, grouting (U.S. Bureau of Reclamation, 1996), or deep foundations. Where possible, a system of subsurface drains to collect and carry groundwater away is the preferred mitigation technique, but drains require periodic cleaning and other long-term maintenance. The final design approved for the proposed facility should consider the results of the groundwater investigation.

REFERENCES

Ashland, F.X., Giraud, R.E., and McDonald, G.N., 2005, Groundwater-level fluctuations in Wasatch Front landslides and adjacent slopes, northern Utah: Utah Geological Survey Open-File Report 448, 22 p.

Ashland, F.X., Giraud, R.E., and McDonald, G.N., 2006, Slope-stability implications of groundwater-level fluctuations in Wasatch Front landslides and adjacent slopes, northern Utah, *in* 40th Symposium on Engineering Geology and Geotechnical Engineering, May 24–26, 2006: Logan, Utah State University, 12 p.

Hely, A.G., Mower, R.W., and Harr, C.A., 1971, Water resources of Salt Lake County, Utah, Department of Natural Resources Technical Publication Number 31, 244 p.

International Code Council, 2009a, International building code: Country Club Hills, Illinois, International Code Council, 678 p.

International Code Council, 2009b, International residential code for one- and two-family dwellings: Country Club Hills, Illinois, International Code Council, 870 p.

National Weather Service Forecast Office, 2009, Salt Lake City, Utah—Period of record monthly climate summary (10/1/1928 to 9/30/2007): Online, http://www.wrh.noaa.gov/slc/climate/slcclimate/SLC/fig5.php, accessed March 26, 2009.

Solomon, B.J., Biek, R.F., and Smith, T.W., 2007, Geologic map of the Magna quadrangle, Salt Lake County, Utah: Utah Geological Survey Map 216, scale 1:24,000.

Thiros, S.A., 1995, Chemical composition of groundwater, hydrologic properties of basin-fill material, and groundwater movement in Salt Lake Valley, Utah: Department of Natural Resources Technical Publication No. 110-A, 59 p.

U.S. Bureau of Reclamation, 1996, Groundwater manual—a guide for the investigation, development, and management of groundwater resources (second edition): Washington, D.C., U.S. Bureau of Reclamation, 693 p.

U.S. Natural Resources Conservation Service, 2006, Soil survey geographic (SSURGO) database for Salt Lake area, Salt Lake County, Utah: Online, http://soildatamart.nrcs.usda.gov/, accessed September 2008.