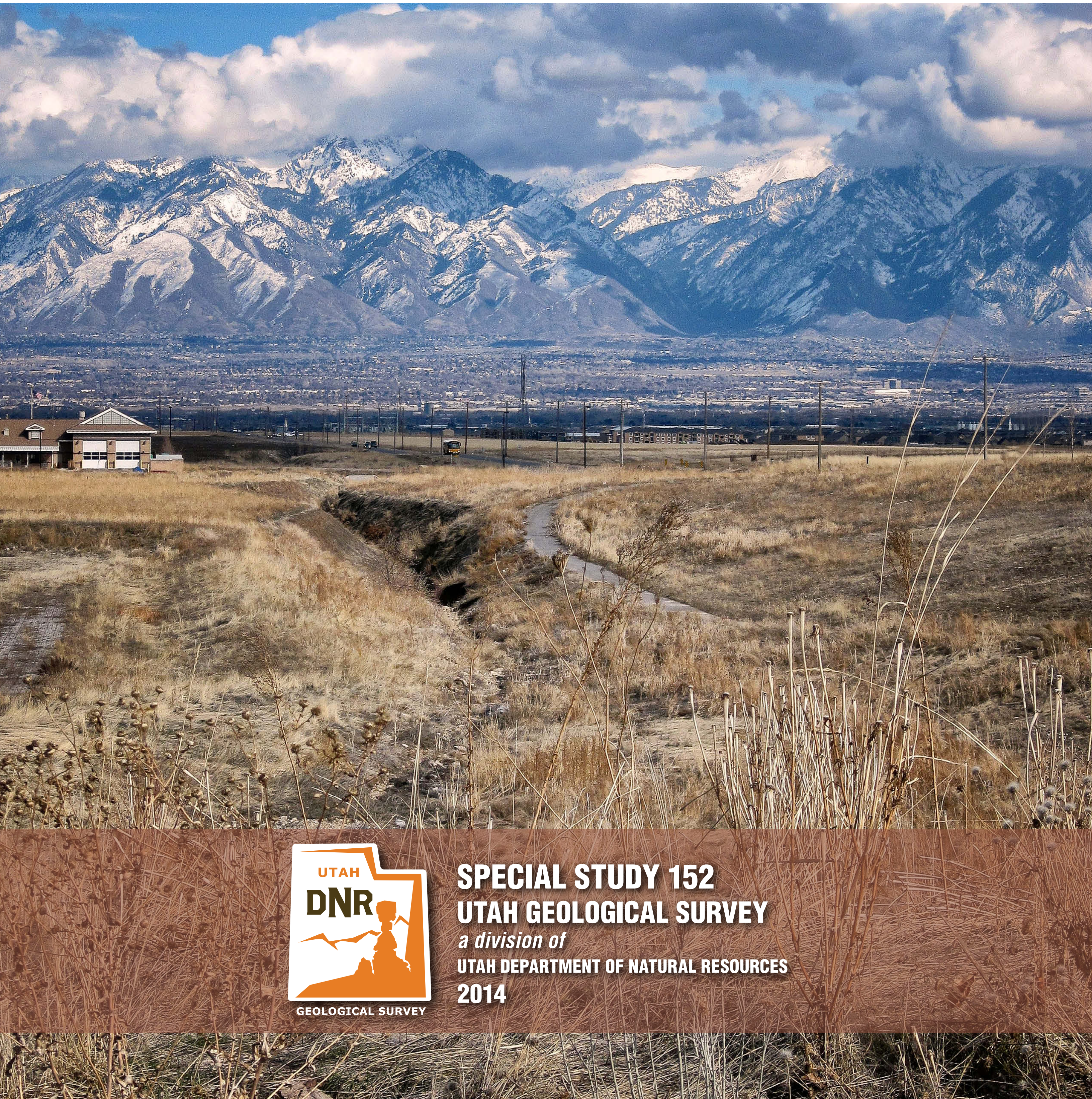
GEOLOGIC HAZARDS OF THE COPPERTON QUADRANGLE, SALT LAKE COUNTY, UTAH

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



SPECIAL STUDY 152
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Cover photo: View east towards the Wasatch Mountains from the Copperton quadrangle.

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PUBLICATIONS
contact
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UTAH GEOLOGICAL SURVEY
contact
1594 W. North Temple, Suite 3110
Salt Lake City, UT 84114
telephone: 801-537-3300
website: geology.utah.gov

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

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ABSTRACT

The Copperton quadrangle, in the southwest portion of 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 Copperton quadrangle incorporates geologic, hydrologic, soil, and geotechnical information to identify where geologic hazards may exist, and where detailed, site-specific, geotechnical/geologic-hazard investigations are necessary.

This study provides maps and information for 10 geologic hazards including shallow groundwater, liquefaction, surface fault rupture, flooding, landsliding, rock fall, radon, collapsible soil, expansive soil and rock, and shallow bedrock. Historically, the most widespread hazard in Utah on an annual basis is flooding. Flooding is of special concern because it occurs frequently, can cause significant damage to facilities, and can be life threatening. Landslides and rock falls are of growing concern as development increases on hillsides, where development is often favored due to scenic vistas and aesthetics. Large earthquakes are rare events in the Copperton 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 rarely are life threatening (except for indoor radon). However, they are potentially costly when not recognized and properly accommodated in project planning and design.

INTRODUCTION

This study provides maps and information on 10 geologic hazards in the Copperton quadrangle. The Copperton quadrangle is in southwestern Salt Lake Valley about 15 miles (25 km) from downtown Salt Lake City, and includes areas 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.

Purpose and Scope

Geologic-hazard mapping is a multidisciplinary, dynamic process that uses a variety of available data to create an integrated product intended for multiple uses. 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 Copperton quadrangle (figure 1). We compiled the data and created the maps for this study at a scale of 1:24,000 (1 inch = 2000 feet) using a geographic information system (GIS). This approach results in geologic-hazard maps that incorporate data and methods from a variety of scientific disciplines including engineering geology, geomorphology, aerial-photography analysis, GIS technology, and geologic field mapping.

The geologic-hazard maps are designed as an aid for general planning to indicate areas where detailed, site-specific geotechnical/geologic-hazard investigations are recommended. 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. These maps are based on a geologic-hazard analysis of the Copperton quadrangle. The geologic hazards addressed include shallow groundwater, liquefaction, surface fault rupture, flooding, landsliding, rock fall, indoor radon, collapsible soil, expansive soil and rock, and shallow bedrock.

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, (3) compiling a digital geotechnical database incorporating test data, borehole logs, and other information from existing geotechnical/geologic-hazard reports in the study area, (4) field mapping, and (5) preparing this report and maps describing each geologic hazard. Other hazards than mapped for this study may be present within the quadrangle that may affect existing and future development.

Previous Work

Christenson and Shaw (2008) compiled selected, existing geologic-hazard investigations for the Wasatch Front into a GIS database. Their maps include the Copperton quadrangle and present information on debris-flow, surface-fault-rupture,

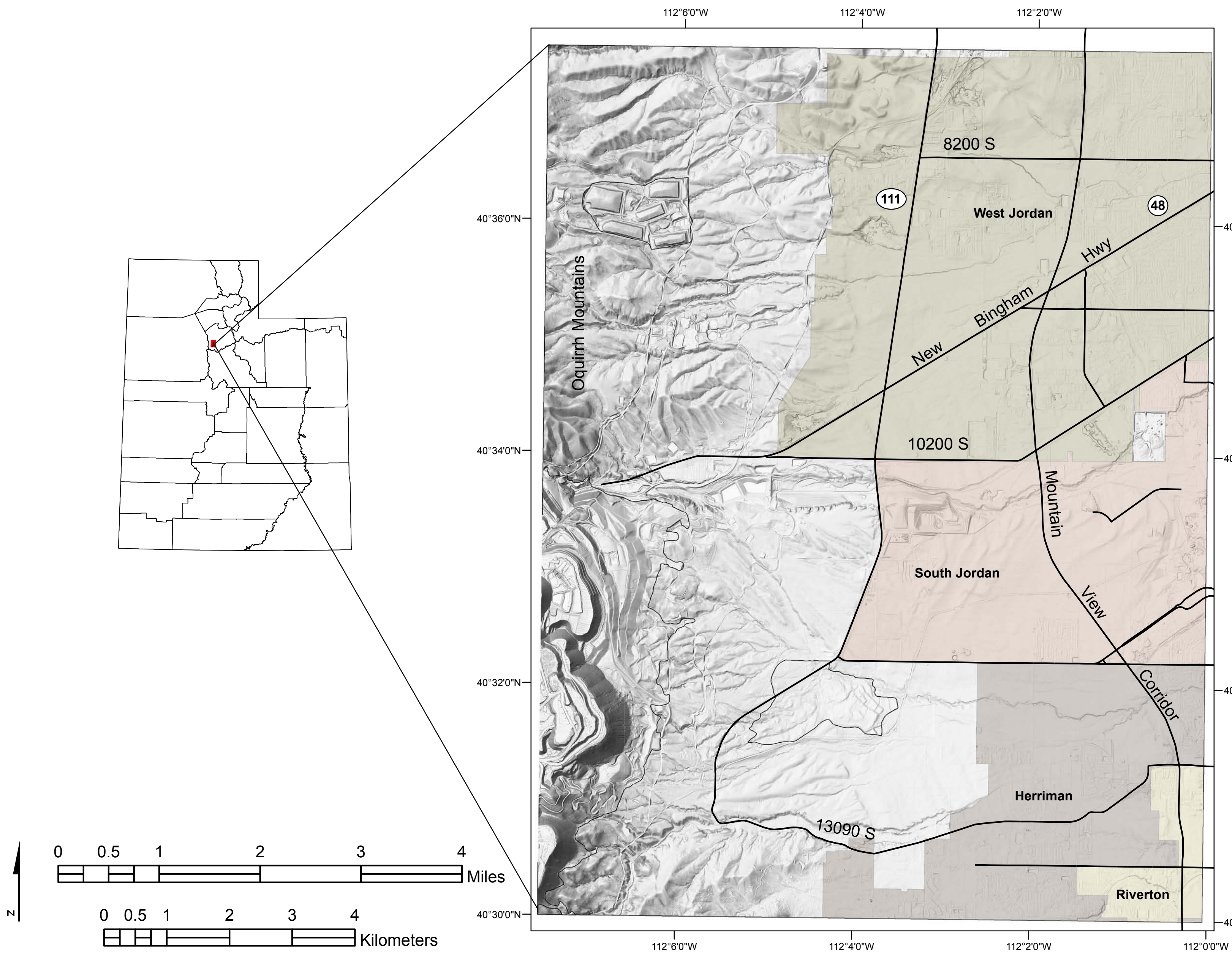

Figure 1. Index map of the Copperton quadrangle showing principal geographic features including boundaries of cities and towns (unshaded areas are unincorporated Salt Lake County, including Copperton) and major transportation routes (AGRC, 2006).

landslide, and liquefaction hazards. Other previous geologic-hazard investigations that encompass the Copperton quadrangle include investigations of:

- earthquake site conditions (McDonald and Ashland, 2008),
- earthquake hazards associated with a scenario magnitude (M) 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, 2006; Olsen and others, 2007; Hinckley, 2010), and
- radon-hazard potential (Black, 1996).

Additionally, recent geologic mapping (Biek and others, 2007) and geotechnical/geologic-hazard investigations have greatly increased our understanding of the area's geology and hazards.

Setting

The Copperton quadrangle includes the unincorporated town of Copperton (in its entirety) as well as parts of the cities of West Jordan, South Jordan, Riverton and Herriman. Principal transportation routes crossing the study area include State Route (SR) 111, SR 48 (New Bingham Highway), 11800 South, and Mountain View Corridor (figure 1).

Elevations in the quadrangle range from approximately 6725 feet (2050 m) in the Oquirrh Mountains, to 4658 feet (1420 m) in the northeast corner 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 approximately 12 miles (19 km) northwest of the town of Copperton, and at approximately the same elevation, was 17.2 inches (43.6 cm) from November 1, 1924, to December 31, 2009 (Western Regional Climate Center [WRCC], 2010). Precipitation in the Oquirrh Mountains bordering the Copperton quadrangle on the west, is more than 5 inches (13 cm) greater than in the valley, based on WRCC (2010) data for the Bingham Canyon weather station from December 1, 1940, to October 31, 1974. Most precipitation is associated with storms from the north Pacific Ocean during fall, winter, and spring. Winter precipitation occurs primarily as snow. Summer temperatures at lower elevations in the study area commonly exceed 90° Fahrenheit (°F) (32.2°C); the November 1, 1924, to December 31, 2009, average maximum temperature for July at the Garfield weather station is 91.5°F (33.1°C), and the January 1, 1948, to December 31, 2009, average maximum temperature for July at the Salt Lake International Airport weather station is 92.8°F (33.8°C) (WRCC, 2010). The dominant vegetation on the valley floor includes various types of perennial grasses. However, in the north part of the quadrangle, where shallow groundwater is present and flooding can be frequent, greasewood and Russian olive trees dominate. As the elevation rises along the valley margins, vegetation changes to a variety of shrubs, including sagebrush.

These maps are printed on a USGS topographic base map published in 1999, that conforms to the North American Datum of 1983 (NAD 83). However, the boundary of the base map conforms to the North American Datum of 1927 (NAD 27) resulting in a slight offset in boundaries and a gap on the west edge of the map with no topographic data. The hazard mapping is in NAD 83.

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 and the eastern boundary of the Basin and Range physiographic province (Stokes, 1977). The Oquirrh Mountains are composed primarily of Pennsylvanian and Permian sedimentary rocks and Tertiary sedimentary and volcanic rocks. Additionally, hydrothermal solutions introduced in conjunction with Tertiary intrusive activity caused the precipitation of ore and gangue minerals 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, in the southwest corner of the Copperton quadrangle, which is one of the largest copper mines in the world. The bedrock in the vicinity of the Copperton quadrangle was deformed by 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 Salt Lake Valley), and the Oquirrh fault zone (at the western base of the Oquirrh Mountains) are the most prominent and youngest structures (e.g., Holocene age) associated with basin-and-range extensional faulting in the region.

Salt Lake Valley is in the Great Basin geographic area, characterized by its internal drainage for much of the past 15 million years. The surficial valley sediments were mostly deposited by late Pleistocene Lake Bonneville (Oviatt and others, 1992, 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 35,000 years ago (CRONUS-Earth Project, 2005), and was in part contemporaneous with the most recent Rocky Mountain glacial advance, the Pinedale glaciation (Lips and others, 2005). Four major regional shorelines—Stansbury, Bonneville, Provo, and Gilbert—associated with transgressive (rising) and regressive (lowering) phases of Lake Bonneville, are recognized in Salt Lake Valley. The Bonneville and Provo shorelines are preserved within the Copperton quadrangle. At the higest level of Lake Bonneville the Bonneville shoreline formed, evident in the southern part of the Copperton quadrangle as the highest topographic 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 18,000 years ago (Miller and others, 2013), 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 shoreline formed on the lower slopes of the Oquirrh Mountains. About 15,000 years ago, a warming climate induced further lowering of the lake level (Godsey and others, 2005), and Lake Bonneville began a decline to the current level of Great Salt Lake.

More details on the stratigraphy, structure, and geologic resources of the Copperton quadrangle and additional references are included on the geologic map of the quadrangle (Biek and others, 2007). Additionally, studies of the West Valley fault zone (Keaton and Currey, 1993; Keaton and others, 1993; DuRoss and Hylland, 2012), 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.

HAZARDS

The early recognition and mitigation of geologic hazards can reduce risk to life and property. Hazard mapping is essential to identify areas where further investigations are necessary to determine risk, hazard extent, and needed mitigation measures. On an annual basis, the most common and damaging geologic hazard in Utah, and affecting the Copperton quadrangle, is flooding. Because of their potentially wide distribution, frequent occurrence, and destructive nature, floods will likely be the principal geologic hazard in the quadrangle with which planners and others will contend in the future.

Landslides and rock falls are of growing 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. Landslide 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 between existing landslides and 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 along 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 in the Copperton quadrangle, but active faults in the quadrangle and surrounding area are capable of producing earthquakes of M 6.5 or greater (Keaton and others, 1993; Lund, 1996; Solomon and others, 2004; DuRoss and Hylland, 2012). 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 extending from northern Montana to northwestern Arizona (figure 2). Hazards associated with 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. 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. However, foundation conditions (type of soil or rock) and the type and quality of construction play large roles in determining the extent of ground shaking damage.

The Copperton quadrangle may experience significant ground shaking due to nearby faults, primarily the West Valley fault zone and the Wasatch fault zone, but also the Harkers fault and an unnamed fault in the southwest part of the quadrangle for which the time of latest movement is not known. Numerous earthquakes greater than M 4 have occurred in proximity to the Copperton quadrangle over the past century, including the 1962 Magna M 5.2 earthquake and the 1992 Western Traverse Mountains M 4.2 earthquake (Christensen, 1992; University of Utah Seismograph Stations, 2010a; figure 3). The Magna earthquake resulted in minor damage to buildings in several cities and towns within one mile (1.6 km) to the southwest of the earthquake epicenter, which is approximately 5 miles (8 km) north of the Copperton quadrangle (figure 3). Newspaper articles, photographs, and personal accounts of the Magna earthquake can be viewed on the University of Utah Seismograph Stations' (2010a) website. Eldredge and O'Brien (2001) also 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

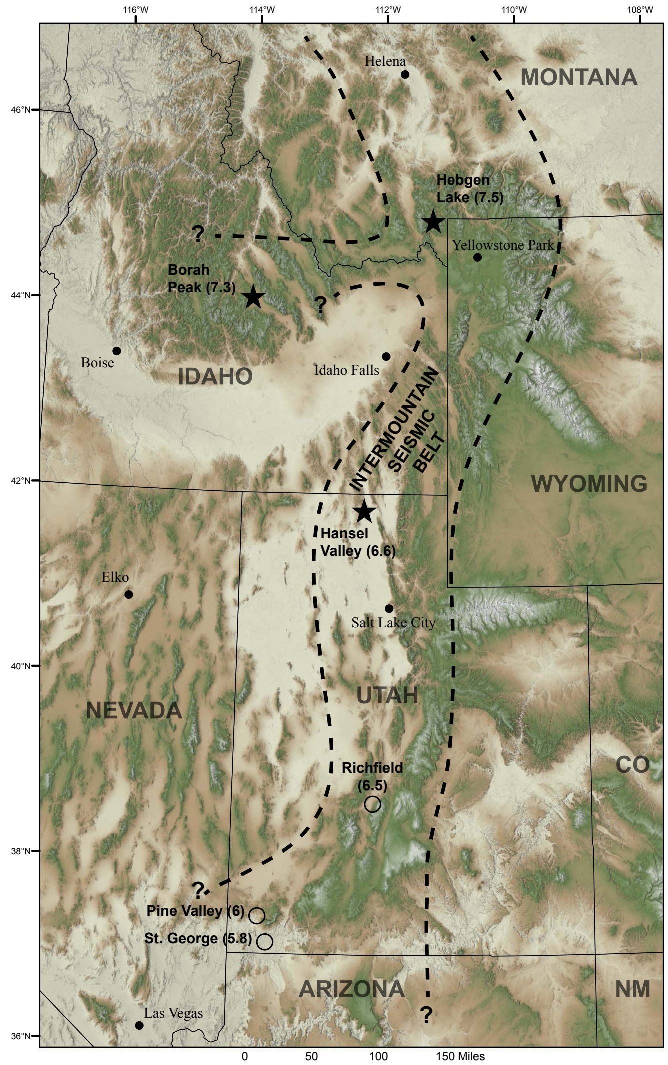

Figure 2. *The Intermountain Seismic Belt (ISB), earthquakes that produced surface-faulting in the ISB (stars), and significant historical, non-surface faulting earthquakes in Utah (open circles), with earthquake magnitude in parentheses (modified from Arabasz and others, 1992).*

for earthquakes in Utah, *Putting Down Roots in Earthquake Country,* which is available online at http://ussc.utah.gov/putting_down_roots.html.

Several different studies related to ground shaking have been completed or are ongoing for Salt Lake Valley (Wong and others, 2002; McDonald and Ashland, 2008; Magistrale and others 2009). For this reason, we did not complete a ground-shaking-hazard map or analysis for the Copperton quadrangle for this study. The effects of large earthquakes must be reduced through land-use planning, adoption and enforcement of modern seismic building codes (International Code Council, 2009a; International Code Council, 2009b), and disaster preparedness planning and drills.

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 the risk of lung cancer, but effective techniques are available for reducing indoor radon levels in existing construction and preventing dangerous levels in new construction.

Shallow Groundwater

Groundwater is found in saturated zones beneath the land surface in soil and rock at various depths. Shallow groundwater levels typically are dynamic and fluctuate in response to a variety of conditions; groundwater levels may rise or fall in response to long-term climatic change, seasonal precipitation, irrigation, and the effects of 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. Groundwater can change the physical and chemical nature of rock and soil, cause soils susceptible to expansion and collapse to activate, and can be a contributing factor to slope instability (Wieczorek, 1996; Ashland and others, 2005, 2006). During moderate to large earthquakes, groundwater within approximately 50 feet (15 m) of the ground surface can cause 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. 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. A 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 layers.

Surficial deposits in the quadrangle are highly variable and range from impermeable to moderately permeable lacustrine silt, sand, and gravel (Biek and others, 2007). Groundwater data in the quadrangle are limited outside areas of recent development; therefore, perched water may extend outside of the mapped zone of shallow groundwater (plate 1). Perched groundwater and seasonally shallow groundwater may locally contribute to development problems in areas not having persistent shallow groundwater.

Our mapping focused on shallow groundwater including the

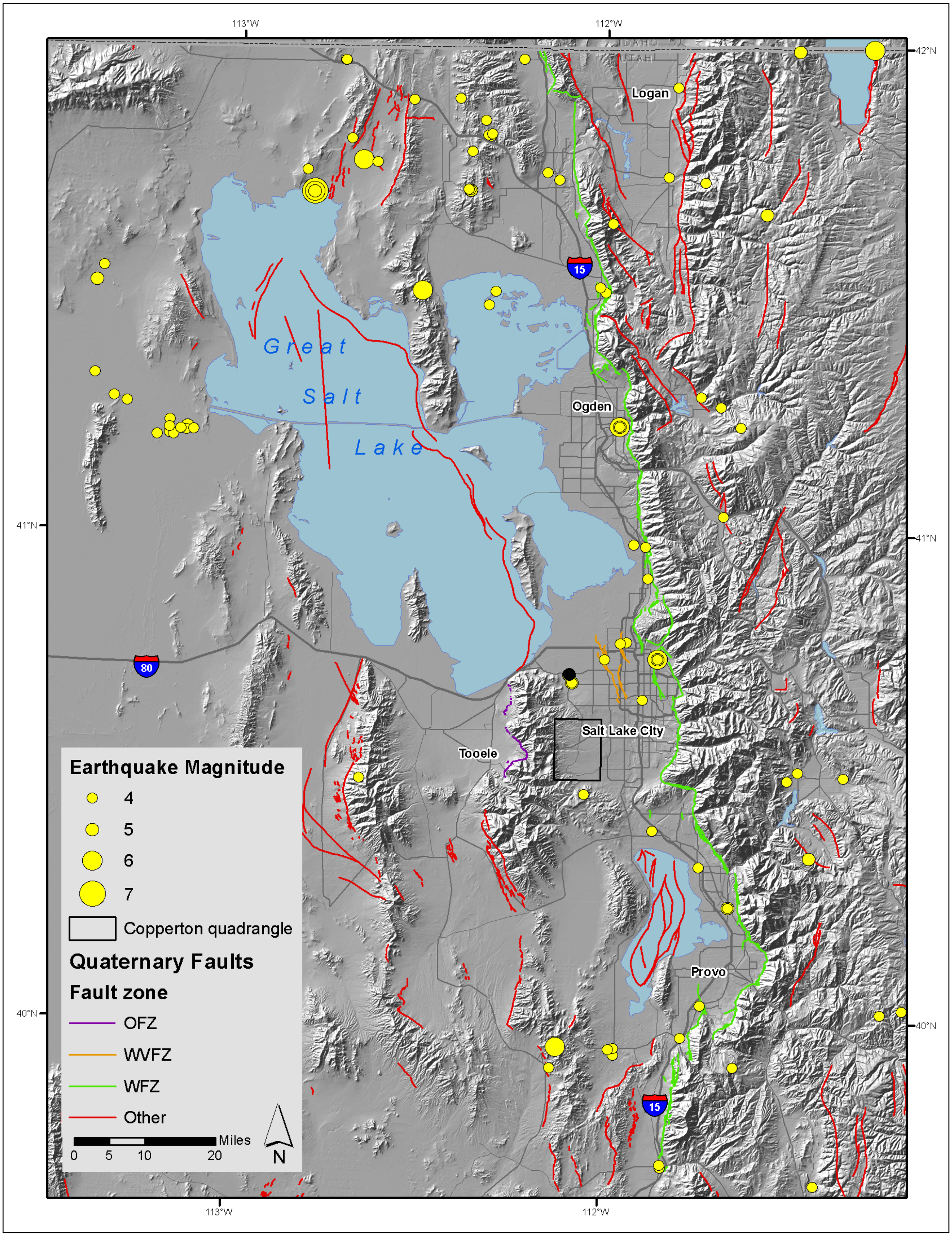

Figure 3. *Earthquake epicenters > M 4 in the Wasatch Front region from 1850 to 2009 (University of Utah Seismograph Stations, 2010b) and major Quaternary faults in the region (Black and others, 2003), including the Oquirrh fault zone (OFZ), West Valley fault zone (WVFZ), and Wasatch fault zone (WFZ). The area outlined in black shows the Copperton quadrangle. The black dot to the north of the Copperton quadrangle shows the epicenter of the 1962 M 5.2 Magna earthquake.*

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

To evaluate shallow groundwater potential (plate 1) we used six main sources of data: (1) recent Utah Geological Survey (UGS) geologic mapping (Biek and others, 2007), (2) a geotechnical database compiled by the UGS, (3) previous groundwater investigations, (4) water-well drillers' logs on file with the Utah Division of Water Rights (UDWR, 2009), (5) private industry water well data, and (6) the Natural Resources Conservation Service (NRCS) *Soil Survey Geographic (SSURGO) Database for Salt Lake Area, Salt Lake County, Utah* (NRCS, 2006).

We obtained groundwater-level data from geotechnical/geologic-hazard investigations and water well logs and incorporated the data into a geotechnical database. The NRCS maps the occurrence of wet or potentially wet soil conditions. Wet conditions are defined by the NRCS as soils in which depth to groundwater is less than 60 inches (152 cm), and potentially wet soil conditions are defined as poorly drained, fine-grained soils that may develop shallow groundwater locally when rates of water application exceed the soil's drainage capacity. These data provide the base for our shallow-groundwater-potential maps. Mapped geologic units were overlain onto the NRCS base and were used as a modifier where necessary, such as in areas of bedrock or geologic units that add conflicting data to the NRCS descriptions at depths greater than 5 feet (1.5 m) below the ground surface. We also modified the NRCS units where depth to groundwater was observed to be shallow (less than or equal to 10 feet [3 m]) in geotechnical boreholes and water-well logs. To account for temporal and seasonal fluctuations in groundwater, we used the most conservative (shallowest) depth to groundwater reported in an area.

Our shallow-groundwater-potential map (plate 1) 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 classify three shallow-groundwater-potential categories 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, or actual depth to groundwater.

Liquefaction

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. Figure 4 illustrates the four principal types of liquefaction-induced ground failure. Liquefaction typically occurs within approximately 50 feet (15 m) of the ground surface (Seed, 1979), 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; Youd and Gilstrap, 1999). However, perched groundwater, locally saturated soils, and changes in local and regional water management patterns, along with seasonal variations of the water table, must also be considered when evaluating liquefaction hazard (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. All of the following conditions must be present for liquefaction to occur:

- the soils must be submerged below the water table,
- the soils must be loose/soft to moderately dense/stiff,
- the ground shaking must be intense, and
- the duration of ground shaking must be sufficient for the soils to lose their shearing resistance.

To evaluate liquefaction susceptibility (plate 2) we used four main sources of data: (1) recent UGS geologic mapping (Biek and others, 2007), (2) a geotechnical database compiled by the UGS, (3) the NRCS *Soil Survey Geographic (SSURGO) Database for Salt Lake Area, Salt Lake County, Utah* (NRCS, 2006), and (4) our shallow groundwater potential mapping. We assigned a liquefaction susceptibility classification of low, very low, or not susceptible based on geologic and groundwater conditions.

We used geologic mapping, NRCS soil data, and soil borehole 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), and integrated these 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 low, very low, or not susceptible based on textural characteristics and cementation (plate 2).

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

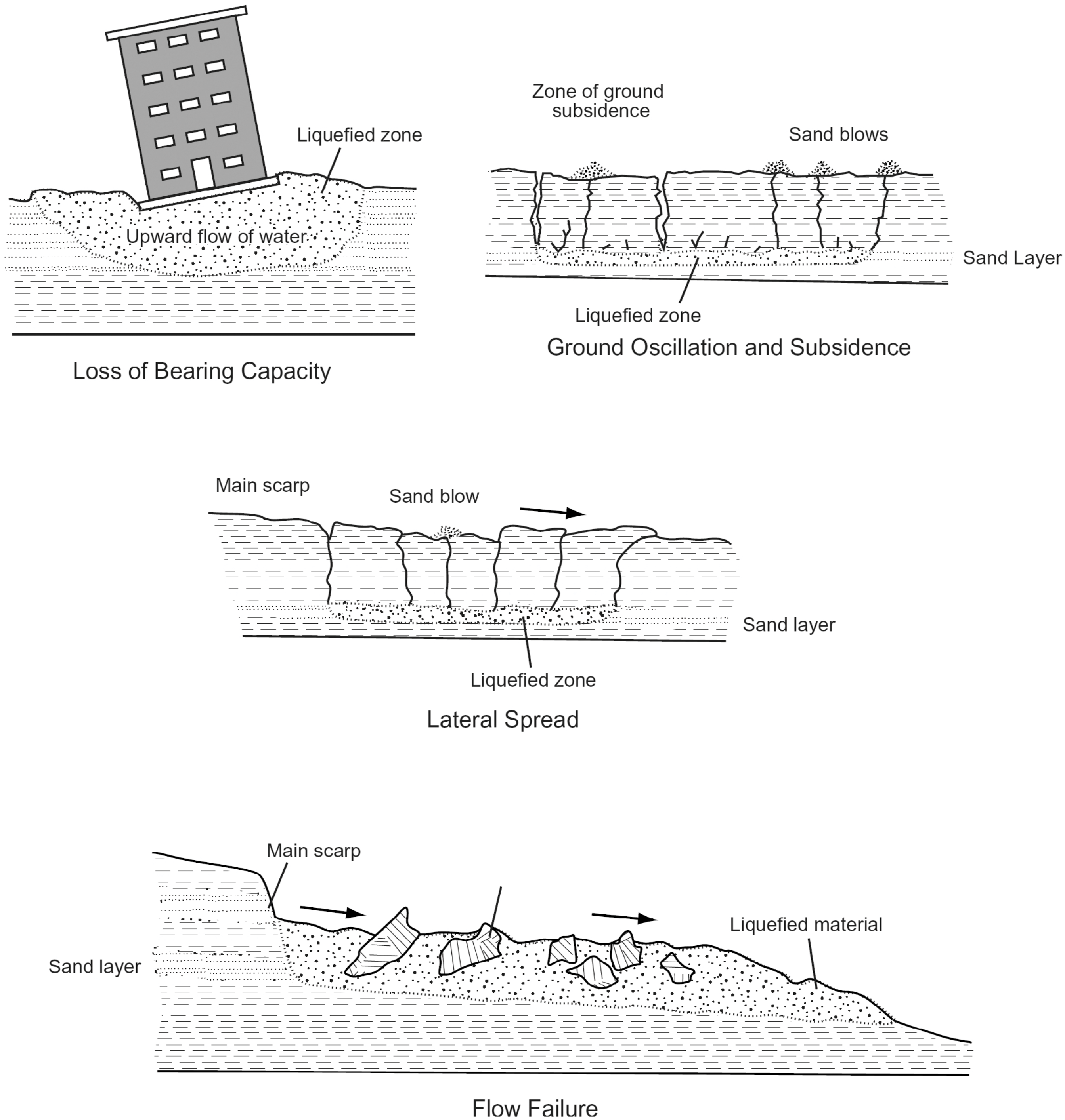

Figure 4. *Four principal types of liquefaction-induced ground failure. Arrows indicate direction of ground movement (modified from Youd, 1984).*

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 poorly sorted sands and gravels where depth to groundwater is likely greater than 50 feet (15 m) below the ground surface but shallow groundwater potential mapping identifies soil conditions likely to develop perched groundwater are mapped as low susceptibility. 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 very low susceptibility. Areas of sandy to fine-grained soils and perched or seasonally high groundwater may increase liquefaction susceptibility within the mapped low and very low susceptibility areas. 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."

The liquefaction susceptibility map (plate 2) does not integrate expected 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 is ongoing at the University of Utah in collaboration with the Utah Liquefaction Advisory Group (ULAG, http://geology.utah.gov/ghp/workinggroups/ulag.htm) and other universities (Bartlett and others, 2005, 2006). The liquefaction susceptibility map also does not indicate if liquefaction of subsurface material will manifest at the surface, nor does it differentiate ground-failure types or amounts, both of which are required to fully assess the hazard and evaluate 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. Minimum requirements for liquefaction investigations are detailed in the International Building Code (IBC) (International Code Council, 2012a), and are implied in the International Residential Code (IRC) (International Code Council, 2012b), which applies to the design and construction of one- and two-family dwellings and townhouses. The 2012 IBC Section 1803.5.11 (p. 394) requires a liquefaction evaluation if a structure is in Seismic Design Category C, D, E, or F, and 2012 IBC Section 1803.5.12 (p. 394) 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. 73) 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 1613.3.3. Seismic design categories are determined on a site-specific basis, and vary throughout the Copperton quadrangle depending on IBC Site Class, defined in IBC section 1613.3.2, maximum considered earthquake ground motions, and the IBC Risk Category of the proposed structure. Risk Categories are based on the nature of the structure's use and occupancy and are described in IBC Section 1604.5 (p. 336) and table 1604.5 (p. 3336). The IBC specifies four Risk Categories (I, II, III, and IV). Risk 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. Risk Category II includes single and multi-family residences, and those buildings and other structures not listed in Risk Categories I, III, and IV, including single-family homes and townhomes. Risk Category III includes buildings and other structures, such as schools, that represent a substantial hazard to human life in the event of failure. Risk 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) stipulates the minimum requirements for liquefaction investigations prior to development. Table 1 shows the current Salt Lake County requirements based on intended land use and incorporates the corresponding IBC occupancy category. Martin and Lew (1999) provide guidelines for conducting both reconnaissance (screening) and detailed (quantitative) liquefaction investigations. In conjunction with the Salt Lake County requirements, we recommend at a minimum:

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

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

Surface Fault Rupture

Among the potential damaging effects of large earthquakes is surface fault rupture, which occurs when fault movement at depth propagates upward 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 (figure 5a). 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 (figure 5b) by secondary faulting may accompany surface fault rupture, resulting in a zone of deformation along the fault trace that

Table 1. *Liquefaction investigations and reports required prior to development approval in Salt Lake County. Modified after Salt Lake County Geologic Hazard Ordinance table 19.75.050 (Salt Lake County, 2010).*

Land Use and IBC Risk Correlation		Liquefaction Potential	
Land Use (Type or Facility)	**IBC Risk Category[1]**	**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[2]	No
Industrial and commercial buildings (>5,000 sq. ft.)	III	Yes	No
Residential-single family lots/single family homes	II	No[2]	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[2]	No

[1]*International Code Council, 2012a*

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

can be tens to hundreds of feet wide. Surface fault rupture, while of limited areal extent when compared to ground shaking, can have serious consequences for structures or other facilities that lie along or across the rupture path.

To evaluate surface-fault-rupture hazard (plate 3) we used five main sources of data: (1) recent UGS geologic mapping (Biek and others, 2007), (2) the *Quaternary Fault and Fold Database and Map of Utah* (Black and others, 2003), (3) the *Guidelines for Evaluating Surface-Fault-Rupture Hazards in Utah* (Christenson and others, 2003), (4) aerial photography interpretation, and (5) 2-meter bare earth Light Detection and Ranging (LiDAR) data (Utah Automated Geographic Reference Center [AGRC], 2006).

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)." California has a well-recognized earthquake hazard and was the first state to implement regulations designed to reduce risk from 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 many faults in the province have surface-faulting recurrence intervals (average repeat times) that approach or exceed 10,000 years. They advocate a late Pleistocene age criterion, 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 percent) 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.

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, because of the difficulties in using a single "active" fault definition (WSSPC Policy Recommendation 11-2; first adopted in 1997 as WSSPC Policy Recommendation 97-1, and revised and readopted in 2002, 2005, 2008, and 2011, available at http://www.wsspc.org/policy/files/Adopted/ADOPTED_PR11-2_BRFault.pdf [WSSPC, 2011]). WSSPC Policy 11-2 recommends that the following definitions of fault activity be used to categorize potentially hazardous faults in the Basin and Range Province:

- 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.

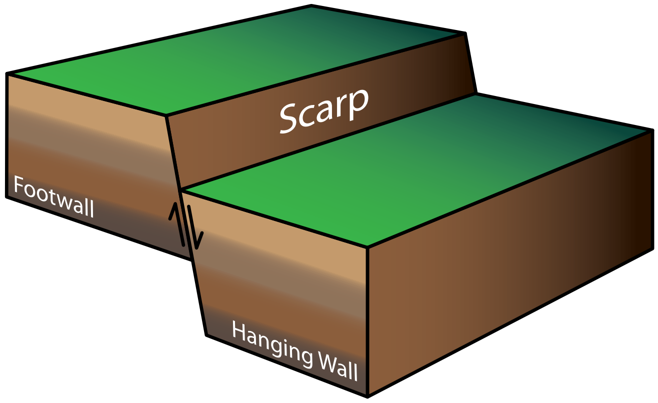

Figure 5a. *Diagram of a normal fault showing the relative movement of the hanging wall and footwall.*

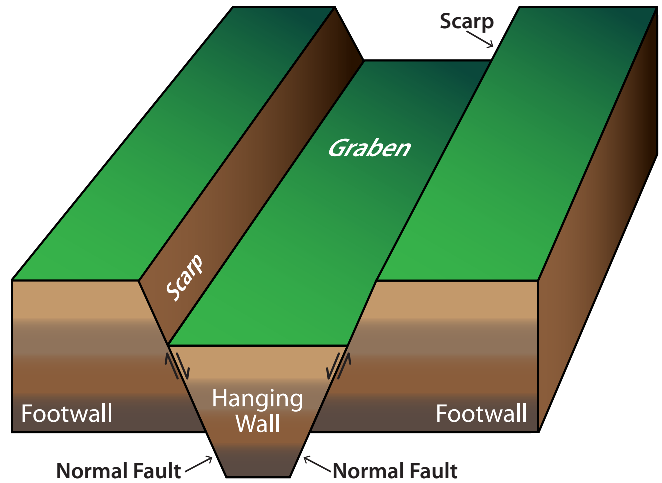

Figure 5b. *Diagram of a graben formed by two normal faults showing the relative movement of the hanging wall and footwall.*

Based upon recent UGS geologic mapping (Biek and others, 2007), we categorize normal faults (where the hanging wall has moved down relative to the footwall [figure 5a]) as well defined, concealed, or approximately located, and established special-study areas for surface-fault-rupture hazard (after Robison, 1993; Christenson and others, 2003; Lund and others, 2008) for each fault category. We consider 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 faults as well defined if UGS 1:24,000-scale mapping (Biek and others, 2007) 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. Christenson and others (2003) provide recommendations for investigating and reporting surface-fault-rupture hazards, and procedures for establishing safe setback distances from active faults in Utah.

Although not well expressed at the surface, buried or approximately located Quaternary faults still may represent a significant surface-fault-rupture hazard and should be evaluated prior to development. Given their uncertain location, the special-study areas around these faults are broader, extending 1000 feet (300 m) from either side of the suspected fault. The surface-fault-rupture hazard map (plate 3) shows potentially active faults on the Copperton quadrangle along which surface faulting may occur. A special-study area is shown around each fault, within which the UGS recommends a site-specific surface-fault-rupture-hazard investigation be performed prior to development. Faults that pose a potential surface-fault-rupture hazard in the Copperton quadrangle are the Harkers fault in the northwestern corner, and two small unnamed faults mapped east of the Harkers fault (Biek and others, 2007). Both the Harkers fault and the unnamed faults are north-northeast-trending normal faults that cut older Quaternary alluvial-fan deposits; however, little else is known about these faults. The hazard from surface fault rupture should be investigated for all critical facilities within the special-study zones for these faults.

Site-specific geotechnical/geologic-hazard investigations can resolve uncertainties inherent in this generalized hazard map 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; http://ugspub.nr.utah.gov/publications/misc_pubs/MP-03-6Guidelines.pdf) includes a detailed rationale for investigating and reporting surface-fault-rupture hazards, and procedures for establishing safe setback distances from potentially 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). Concealed and approximately located faults lack a clearly identifiable surface trace, and therefore may not be 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 water and groundwater, previous subsurface investigations, and other relevant factors.
2. Stereoscopic interpretation of aerial photographs and/or interpretation of LiDAR imagery 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 by a qualified geologist for evidence of faulting as development proceeds.

Flood Hazards

Flooding is the overflow of water onto lands that are normally dry, and is the most commonly occurring 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) hazard affecting Utah.

The flood hazard map (plate 4) shows areas in the Copperton quadrangle that may be susceptible flooding. Several creeks capable of flooding are at least partially within the quadrangle. These include Barneys Creek, Rose Canyon Creek, Butterfield Creek, Bingham Canyon Creek, Midas Creek, and Copper Creek. Several smaller ephemeral drainages contribute to the flood hazard as well. Seasonal weather patterns that deliver moisture to northern Utah also contribute to a high flood hazard. The risk from flooding is significantly increased by wildfires because in burn areas wildfires cause a decrease in water infiltration and an increase in run-off and erosion. Human activities, such as placing structures and constrictions in floodplains, active alluvial fans, or erosion-hazard zones; developing without adequate flood and erosion control; poor watershed management practices (such as overgrazing or allowing indiscriminate off-road vehicle traffic); and the unintentional release of water from an engineered water-retention or conveyance structure (such as a dam or canal) also increase the potential for flooding.

To evaluate flood hazard (plate 4) we used four main sources of data: (1) Federal Emergency Management Agency (FEMA) National Flood Insurance Program Flood Insurance Rate Maps (FIRMs [FEMA, 2009]), (2) recent UGS geologic mapping (Biek and others, 2007), (3) aerial photography interpretation, and (4) 2-meter LiDAR data (AGRC, 2006) to examine past and present drainage patterns. Geologic mapping is critical to determine the distribution of geologically young flood-related deposits, which aids in identifying flood-prone areas and in evaluating their relative susceptibility to flooding and/or debris flow. Active floodplains and low terraces along perennial and larger ephemeral streams, active alluvial fans, and young lacustrine deltaic deposits are mapped as high flood hazard. Normally dry stream channels, floodplains, and low terraces, along with older alluvial-fan deposits, lagoon-fill deposits, and colluvial deposits are mapped as moderate flood hazard. Minor ephemeral drainages are mapped as low flood hazard. Pediment-mantle alluvium is mapped as very low flood hazard. 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 concentrated in drainages. Individual drainages were not mapped due to the topographic complexities and scale limitations of the area.

FEMA-designated flood zones delineated on the FIRMs are overlain on our mapped hazard categories. 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.

Landslide Hazards

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 can range from dry to saturated. However, high moisture content reduces the strength of most deposits susceptible to landslides, and is often a contributing factor to landsliding.

Three broad factors, acting either individually or in combination, contribute to landsliding (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 is 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 landsliding, 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). Landslide triggers may be either static or dynamic. Static conditions include intense rainfall or prolonged periods of above-normal precipitation, rapid snowmelt, added water from irrigation or improper drainage, improper grading, and rapid erosion. Dynamic conditions include earthquakes and other ground 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.

To evaluate landslide susceptibility (plate 5) we used five main sources of data: (1) recent UGS geologic mapping (Biek and others, 2007), (2) previous landslide investigations, (3) aerial photography interpretation, (4) 2-meter LiDAR data (AGRC, 2006), and (5) field mapping and reconnaissance. We classify landslide susceptibility as high, moderate, or low. High landslide susceptibility consists of mapped landslides as well as geologic units that have experienced previous landsliding elsewhere in Utah as identified by geologic mapping and that underlie slopes that equal or exceed a selected critical slope angle. Moderate landslide susceptibility consists of areas having slopes greater than a selected critical slope angle in geologic units having no known prior landsliding. Low landslide susceptibility consists of areas having slopes with a critical angle lower than determined for specific geologic unit and units not likely susceptible to landsliding.

In the Copperton quadrangle, we applied critical slope angles of 10 and 20 degrees based on analysis of landslides in northern Utah within the same geologic units. To determine these slope angles we used GIS to calculate the average slope of each mapped landslide included in the *Landslide Maps of Utah* (Elliott and Harty, 2010) in northern Utah. The landslide slopes were then exported to a spreadsheet based on geologic unit and the average slope angle for each geologic unit was determined. Using mean landslide slopes plus or minus one standard deviation we assigned critical angles to geologic units in the Copperton quadrangle. Similar methodology has been used in other landslide evaluation and susceptibility investigations in similar geologic units to define critical slope (Hylland and Lowe, 1997; Giraud and Shaw, 2007). We assigned a critical angle of 10 degrees to Lake Bonneville deposits and Tertiary volcanic deposits, and 20 degrees to Oquirrh Group deposits.

Although earthquake-induced ground shaking increases the potential for landsliding in susceptible material, the relative landslide susceptibility of the slope material does not change. For example, slopes mapped as having moderate landslide susceptibility are more likely to fail during an earthquake than under static conditions; however, slopes having moderate landslide susceptibility are less likely to fail than slopes having high susceptibility under static and/or dynamic conditions.

The landslide-susceptibility map (plate 5) shows areas of relative landslide susceptibility where site-specific slope-stability conditions (material strength, orientation of bedding and/or fractures, groundwater conditions, and erosion or undercutting) should be evaluated prior to development. A valid landslide-hazard investigation must address all pertinent conditions that could affect, or be affected by, the proposed development, including earthquake ground shaking, perched or irrigation-induced groundwater, and slope modifications. This can only be accomplished through the proper identification and interpretation of site-specific geologic conditions and processes (Hylland, 1996). The analysis of natural and modified slopes for static and/or seismic stability is a challenging geotechnical problem. Blake and others (2002) consider accurate characterization of the following as required for a proper static slope stability analysis:

1. Surface topography.
2. Subsurface stratigraphy.
3. Groundwater 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, can be particularly challenging to accurately characterize.

Additionally, UGS Circular 92, *Guidelines for Evaluating Landslide Hazards in Utah* (Hylland, 1996; http://ugspub.nr.utah.gov/publications/circular/C-92.pdf), 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 pro-

Table 2. Recommended requirements for site-specific landslide-hazard investigations in the Copperton quadrangle.

Landslide Susceptibility	Recommended Site-Specific Investigation
High	Detailed engineering geologic and geotechnical-engineering investigation necessary
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

gressing 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 Copperton quadrangle, in accordance with UGS Circular 92, are shown in table 2.

Salt Lake County's Zoning Ordinance Code prohibits development (including clearing, excavating, and grading) on slopes exceeding 30 percent (16 degrees) and sets aside these areas as natural private or public open space (Salt Lake County, 2010). Also, all roads are restricted from crossing slopes above 30 percent (16 degrees) unless they meet specific requirements and gain authorization (Salt Lake County, 2010).

While it is possible to classify relative landslide hazard in a 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.

Rock-Fall Hazards

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 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 rock 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.

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 bluffs, terraces, and ancient shorelines. 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, though in many cases a specific triggering mechanism is not apparent. Rock falls may also be initiated by ground shaking. Keefer (1984) indicates earthquakes as small as M4 can trigger rock falls.

The rock-fall hazard map (plate 6) shows areas in the Copperton quadrangle that may be susceptible to rock fall. Where no hazard is mapped, rock-fall hazard is either absent or too localized to show on a 1:24,000-scale map. Each hazard category includes three components (figure 6): (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 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 slope.

To evaluate rock-fall hazard (plate 6) we used five main sources of data: (1) recent UGS geologic mapping (Biek and others, 2007), (2) previous landslide investigations, (3) aerial photography interpretation, (4) 2-meter LiDAR data (AGRC, 2006), and (5) field mapping and reconnaissance.

We assigned a hazard designation of high, moderate, or low based on the following rock-fall-source parameters: rock type, joints, fractures, orientation of bedding planes, and potential clast size, as determined by geologic mapping (Biek and others, 2007), as well as slope angle, acceleration zone, and a shadow angle of 20 degrees. We evaluated slopes below rock-fall sources for slope angle, vegetation, clast distribution, clast size range, amount of embedding, and weathering of rock-fall boulders. Table 3 summarizes our recommended requirements for site-specific geotechnical/geologic-hazard investigations related to rock-fall hazards to protect life and safety.

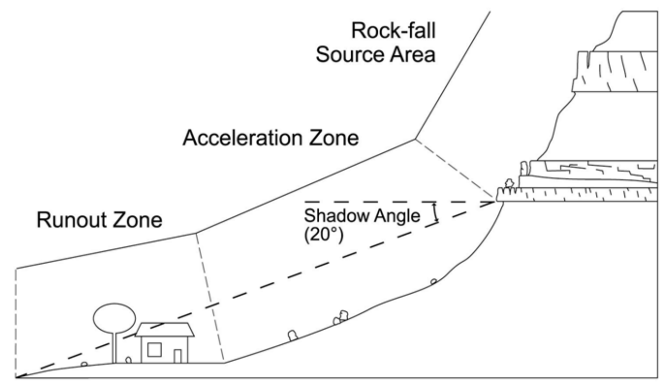

Figure 6. *Components of a characteristic rock-fall path profile (after Lund and others, 2008).*

Radon Hazard

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 the 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 than 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 and shale, and soils derived from these rocks are generally associated with elevated uranium content contributing to high indoor radon levels.

Table 3. *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] *Risk category from International Code Council, 2012a.*
[2] *Property damage possible, but little threat to life safety.*

Soil permeability and groundwater affect 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 having low permeability. Saturation of soil by 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 are highly variable. As a result, indoor radon levels fluctuate and can vary in different 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). Evaluation of actual indoor radon levels in the quadrangle was beyond the scope of this investigation.

To evaluate the radon-hazard potential (plate 7) we used four main sources of data to identify areas where underlying geologic conditions may contribute to elevated radon levels: (1) radon-hazard-potential studies where available, (2) soil permeability data from the NRCS *Soil Survey Geographic (SSURGO) Database for Salt Lake Area, Salt Lake County, Utah* (NRCS, 2006), (3) depth-to-groundwater mapping, and (4) recent UGS geologic mapping (Biek and others, 2007). Using the geologic factors contributing to uranium content, soil permeability, and depth to groundwater, we classified soil and rock units into high and moderate hazard categories based on their potential to generate radon gas and the ability of the gas to migrate upward through the overlying soil and rock (after Black, 1996; table 4). Geologic mapping is important for identifying geologic units having high uranium content, particularly outside of areas covered by previous investigations where radiometric data are limited.

The NRCS reported 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. 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 is assumed to apply to non-soil map units.

Saturation of soil by shallow groundwater (less than approximately 30 feet [9 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 focused on the principal aquifer where it is shallow and unconfined or artesian, and on locally unconfined or perched aquifers 30 feet (9 m) or less below the ground surface.

The map of radon-hazard potential (plate 7) is intended to provide an estimate of the underlying geologic conditions that may contribute to the 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. 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). The radon-hazard potential

Table 4. *Radon-hazard-potential classifications based on geologic factors affecting the ability of radon gas to migrate upward through the overlying soil and rock.*

Geologic Factors	Radon hazard category[1]		
	Low	Moderate	High
Uranium (ppm)	<2	2-3	>3
Soil permeability[2]	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] *Black (1996)*
[2] *NRCS (2006)*

map 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, indoor radon levels can vary greatly between structures located in the same hazard category.

The hazard-potential categories shown 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 nongeologic 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.

Collapsible Soil Susceptibility

Collapsible soils are relatively dry, low-density soils that decrease in volume or collapse under the load of a structure 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, structures, pavements, and underground utilities.

Collapsible soils are present in the Copperton quadrangle and are typically geologically young materials, chiefly Holocene debris-flow sediments in alluvial fans and Pleistocene to Holocene lacustrine and colluvial deposits (plate 8). 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 percent; Owens and Rollins, 1990), all characteristics that result from the initial rapid deposition and drying of the sediments. Alluvial fans are an example of this depositional environment and in many cases have a high collapsible soil hazard. 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 (Williams and Rollins, 1991), although Rollins and Rogers (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 related to urbanization such as irrigation or wastewater disposal.

To evaluate collapsible-soil susceptibility (plate 8) we used two main sources of data: (1) recent UGS geologic mapping (Biek and others, 2007), and (2) the geotechnical database compiled by the UGS. First, we evaluated test data from the geotechnical database; swell/collapse tests (SCT), dry density, and moisture tests are all used to determine collapse potential. Next, we integrated geologic unit descriptions from recent UGS geologic mapping (Biek 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 collapse potential.

Where geotechnical data provide evidence for high collapse susceptibility, as indicated by SCT results exhibiting collapse potential equal to or more than 3 percent (Jennings and Knight, 1975), we assigned two susceptibility categories: highly collapsible soil, where SCT tests indicate collapse potential equal to or more than 5 percent, and collapsible soil A, where SCT tests indicate collapse potential over 3 percent and less than 5 percent. For geologic units in which other geotechnical information (chiefly low density and moisture content) provide evidence for potentially collapsible soils, we delineated a collapsible soil B category using geologic contacts. Where geotechnical data are lacking, we assigned geologic units with a genesis and texture conducive to collapse to the collapsible soil C category. Finally, where older geologic units (Pleistocene) are mapped with no available geotechnical data, but with a genesis or texture permissive of collapse, we assigned the collapsible soil D category. All susceptibility categories represent geologic units having a potential for collapse. Geologic units with SCT results indicating a demonstrated high percentage of collapse dictate 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 maps.

Expansive Soil and Rock Susceptibility

Expansive soil and rock swells as it gets wet, and shrinks as it dries out. These changes in volume can cause cracked foundations and other structural damage to buildings, structures, pavements, and underground utilities (figure 7), heaving and cracking of canals and road surfaces, and failure of wastewater disposal systems. Expansive soil and rock contains 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

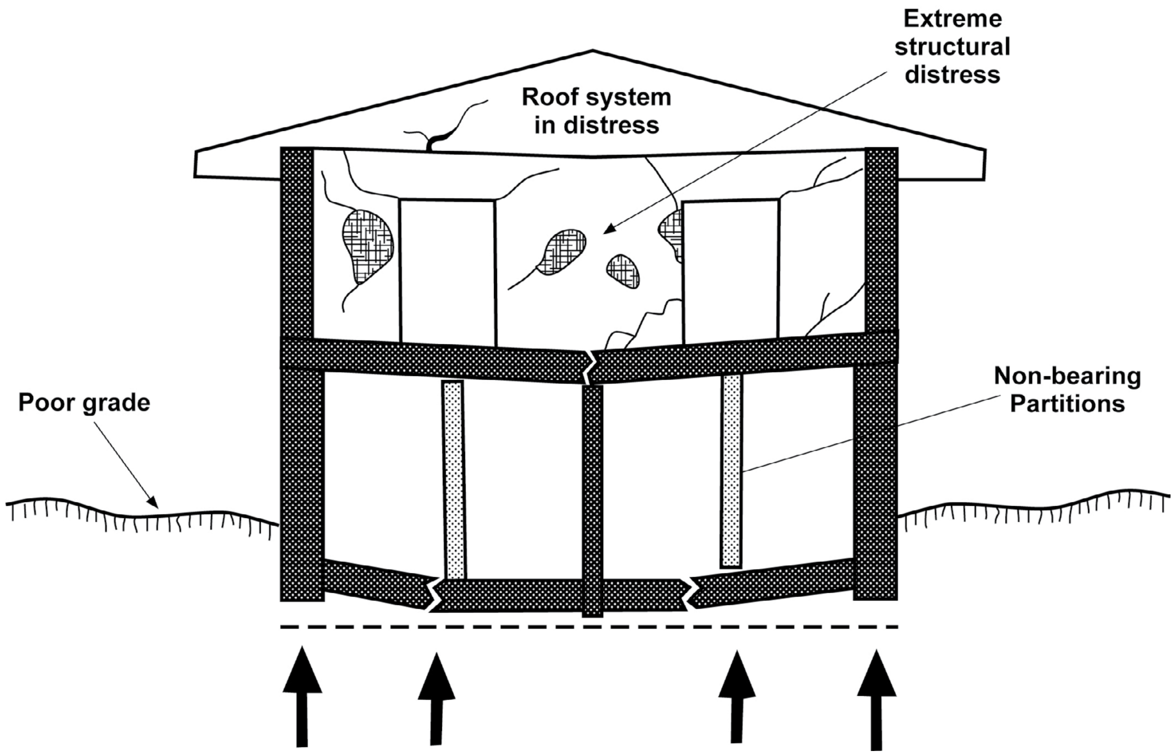

Figure 7. *Typical structural damage to a building from expansive soil (after Black and others, 1999).*

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 can play important roles locally.

To evaluate susceptibility to expansive soil and rock (plate 9) we used three main sources of data: (1) recent UGS geologic mapping (Biek and others, 2007), (2) the geotechnical database compiled by the UGS, and (3) the NRCS *Soil Survey Geographic (SSURGO) Database for Salt Lake Area, Salt Lake County, Utah* (NRCS, 2006). We classified soil and rock units into three categories based on their potential for volumetric change: high, moderate, and low.

The NRCS (2006) assigned a linear extensibility value to soils. Linear extensibility is 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). We compared the ratings presented by the NRCS 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 show elevated levels of swell potential, we use geologic-map data to modify the boundaries between susceptibility categories.

Using geotechnical data in our database, we evaluated liquid limit (LL), plasticity index (PI), SCT tests, and expansion index data for swell potential. SCT tests are the most reliable indicator of swelling potential; we used them as the primary indicator of swell potential, and LL and PI tests in the absence of SCT data.

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 5) 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 IBC and the IRC (International Code Council, 2012a, 2012b), which use PI as one of four criteria to determine if soils are considered expansive, include soils having a PI of 15 or greater in the expansive soil category. In general, PI values equal to or more than 20 can serve as a rough indicator of high swell potential 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 having 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 clay, with an LL less than 50 as having low or medium plasticity.

We identified geologic units containing expansive clay minerals by examining geologic unit descriptions and geotechnical test data from the units. We classified them as having moderate or high swell potential depending on geotechnical test data from the unit and its corresponding NRCS classification. Due to the scale of our mapping, individual sites within any susceptibility category (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.

Table 5. *Correlation between geotechnical tests of soils and expansive-soil susceptibility.*

Test	Susceptibility Category		
	Low	Moderate	High
SCT	0–2%	2–3%	≥ 3%
LL	0–30	20–50	≥ 45
PI[1]	0–15	10–35	≥ 20
Expansion Index[2]	0–50	51–90	>91

[1] Chen (1988)
[2] Nelson and Miller (1992)

Shallow Bedrock

Bedrock formations that are not significantly fractured provide relatively incompressible foundations with high shear strengths, making mechanical compaction of these materials generally ineffective and unnecessary (Christenson and Deen, 1983). The principal problem related to shallow bedrock is difficulty of excavation, particularly in highly resistant bedrock units. Shallow bedrock makes excavations for basements, foundations, underground utilities, and road cuts difficult, can cause areas of perched groundwater, and can create problems for wastewater disposal.

Resistant bedrock crops out at the ground surface in many foothill locations of Utah. Less obvious are areas of shallow bedrock within valleys, where bedrock is overlain by a thin cover of unconsolidated Lake Bonneville and younger alluvial deposits.

To evaluate shallow-bedrock potential (plate 10) we used five main sources of data: (1) recent UGS geologic mapping (Biek and others, 2007), (2) the NRCS *Soil Survey Geographic (SSURGO) Database for Salt Lake Area, Salt Lake County, Utah* (NRCS, 2006), (3) the geotechnical database compiled by the UGS, (4) the UDWR well information program WELL-VIEW (Utah Division of Water Rights, 2009), and (5) field mapping and reconnaissance. We classify shallow bedrock as hard or soft where exposed at the surface, and identified areas of buried shallow bedrock (less than 10 feet [3 m] below the surface).

We used recent geologic mapping (Biek and others, 2007) to identify areas where bedrock crops out at the ground surface, and qualitatively classified bedrock units based on geologic unit descriptions. After identifying bedrock outcrops, we used the restrictive layer data reported by the NRCS (2006) soil survey to identify areas of potentially shallow bedrock. The restrictive layer column identifies areas where bedrock is found less than 6.5 feet (2 m) below the surface. Other restrictive layers, such as duripan and petrocalcic layers, are also identified by the NRCS in western Salt Lake Valley, but they were not considered 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 for excavations, subsurface investigations, wastewater disposal, and can cause perched groundwater.

We used geotechnical borehole logs in the UGS geotechnical database and the UDWR well information program WELL-VIEW (UDWR, 2009) to help identify areas of shallow bedrock. We compared the borehole logs with geologic mapping, NRCS soils mapping, and geotechnical testing information to confirm the existence of shallow bedrock where it was identified by NRCS and to identify other potential areas of shallow bedrock. Correlations between the borehole logs, geologic mapping, geotechnical data, and NRCS information are generally good, but some local discrepancies commonly exist.

MAP LIMITATIONS

The geologic-hazard maps accompanying this report are designed to provide geotechnical engineers, engineering geologists, design professionals, planners, building officials, developers, and the general public with information on the geologic hazards that may affect existing and future development in the Copperton quadrangle. Information provided herein includes the type and location of critical geologic hazards, and recommendations for site-specific investigations to mitigate the hazards. The maps indicate where detailed, site-specific geotechnical/geologic-hazard investigations should be performed. Additionally, the maps can aid local governments in developing geologic-hazards elements for their general land-use plans for development, re-development, planning, regulation, and design in Utah (Christenson and Ashland, 2007). We mapped 10 geologic hazards on the Copperton quadrangle;

however, other hazards may exist that may affect existing and future development.

We recommend performing site-specific geotechnical/geologic-hazard investigations for all development in the Copperton quadrangle. Site-specific geotechnical/geologic-hazard investigations can resolve uncertainties inherent in these generalized hazard maps and help ensure safety by identifying the need for hazard mitigation and/or special construction techniques. As with all maps, these geologic-hazard maps have limitations. The maps are not for use at scales other than 1:24,000, and are not a substitute for site-specific geotechnical/geologic-hazard investigations. The maps are based on limited geologic, geotechnical, and hydrologic data. The quality of each map depends on the quality of the data, which varies by hazard 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 a study area, but their identification may be precluded due to limitations of either data availability or map scale.

ADDITIONAL INFORMATION AND GUIDELINES

In addition to the information contained in this report, the 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 UGS 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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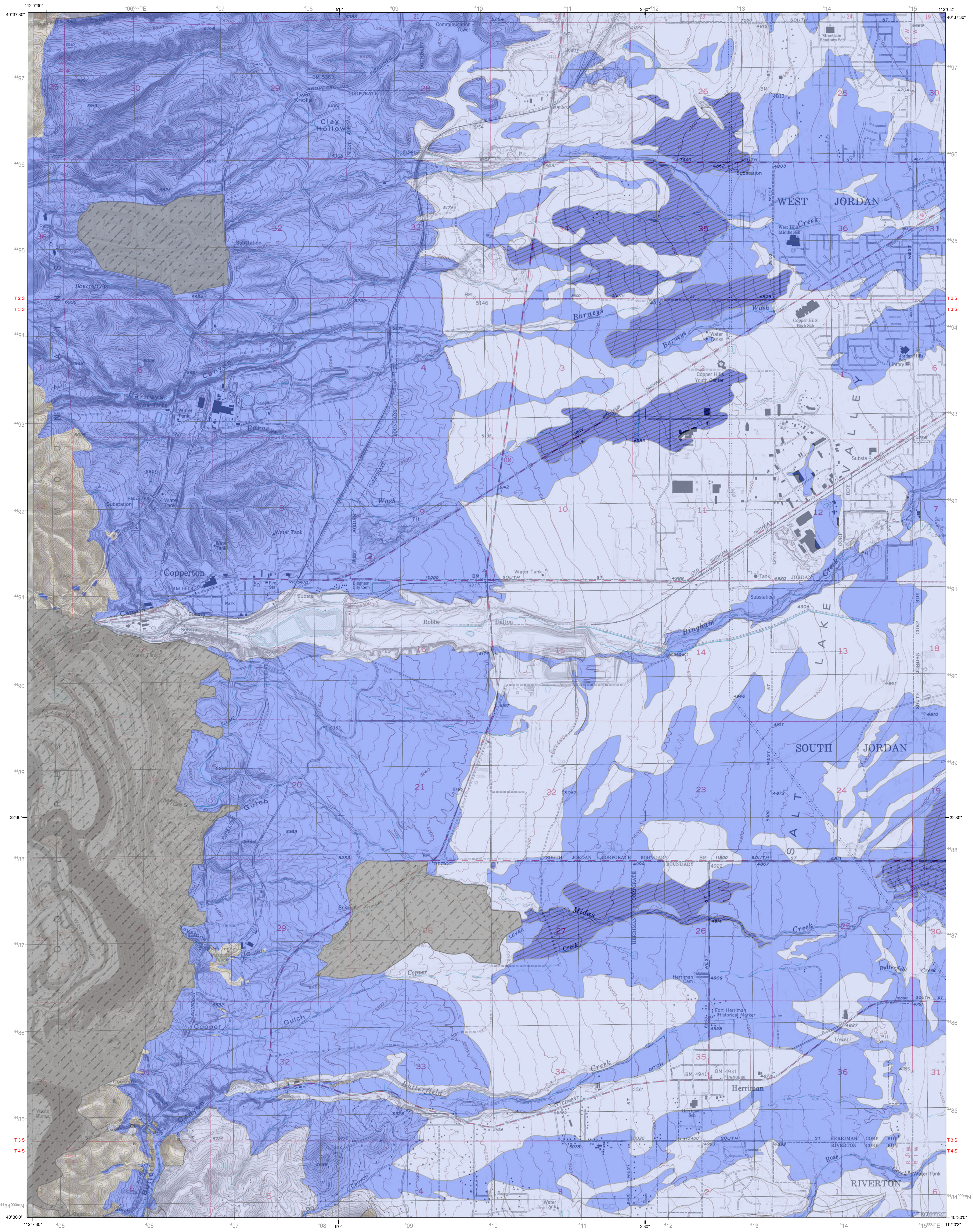

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SCALE 1:24,000

1 0.5 0 1 MILE

5000 2500 0 5000 FEET

1 0.5 0 1 KILOMETER

CONTOUR INTERVAL 20 FEET

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Datum: NAD 1983
Spheroid: Clarke 1886

GIS and Cartography: Jessica J. Castleton and Ben A. Erickson

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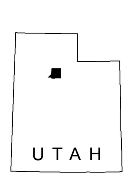
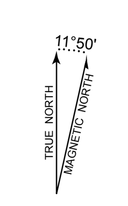


QUADRANGLE LOCATION



APPROXIMATE MEAN DECLINATION, 2014

SHALLOW GROUNDWATER POTENTIAL MAP AS INDICATED BY SOIL INFILTRATION PROPERTIES OF THE COPPERTON QUADRANGLE, SALT LAKE COUNTY, UTAH

by

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

2014

1	2	3
4		5
6	7	8

1. Farnsworth Peak
2. Magna
3. Salt Lake City South
4. Bingham Canyon
5. Midvale
6. Lowe Peak
7. Tickville Spring
8. Jordan Narrows

ADJOINING 7.5' QUADRANGLE NAMES

ISBN 978-1557918994

EXPLANATION

Not Mapped – Area not mapped due to significant and ongoing human disturbance.

SHALLOW GROUNDWATER POTENTIAL CATEGORIES

Shallow Groundwater unit 1 (SGW1) – Area identified as having potentially shallow groundwater, or the possibility of developing shallow groundwater. Includes soils mapped by the Natural Resources Conservation Service (NRCS) as naturally wet, poorly drained or frequently irrigated, and where water-well or geotechnical data indicate a significant area of poorly drained soils characteristics or confining geologic conditions where permanent shallow groundwater (less than 10 feet) may develop. Current groundwater levels may be deeper than 10 feet below the surface; however, construction, irrigation, runoff, and increased precipitation in these areas will likely increase shallow groundwater potential. Following development, landscape irrigation and other sources of urban runoff may cause groundwater levels to rise even higher in these areas.

Shallow Groundwater unit 2 (SGW2) – Area identified as having potentially shallow groundwater, or the possibility of developing shallow groundwater. Includes 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.

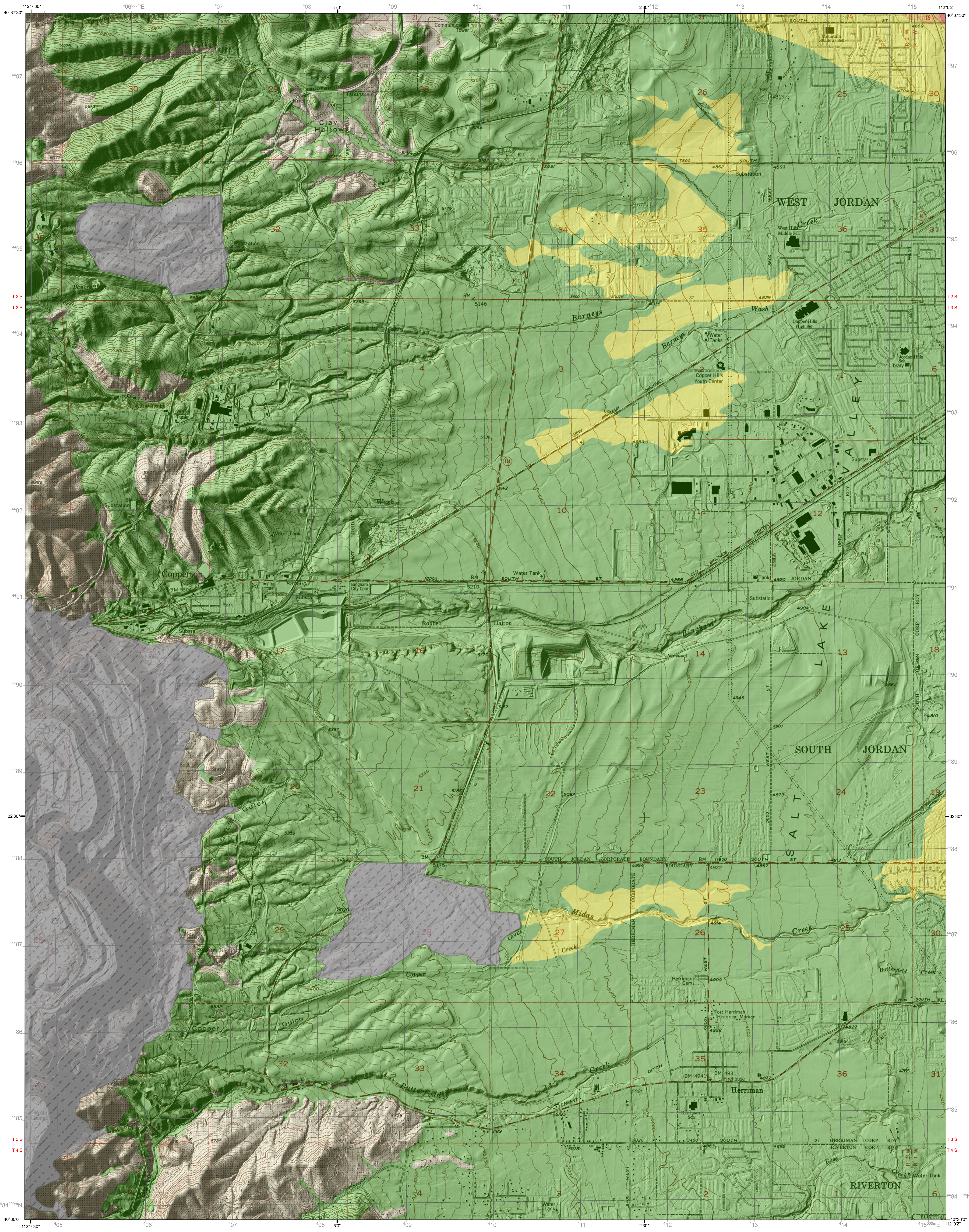
Shallow Groundwater unit 3 (SGW3) – Area identified as having potentially shallow groundwater, or the possibility of developing shallow groundwater. Includes soils mapped by the NRCS as moderately to freely draining soils that are commonly irrigated for agricultural purposes. However, where intense levels of water application occur, 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.

Bedrock

USING THIS MAP

This map shows the location of known and potential areas of shallow groundwater in the Copperton quadrangle; however, the map 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. This map is focused on geologic and soil conditions that may contribute to shallow groundwater potential. Permanent groundwater within the deeper regional aquifer is not likely to be encountered less than 50 feet below the surface on the Copperton quadrangle. The shallow-groundwater-potential map does not differentiate between aquifers and is not intended to model the deeper regional aquifer; instead it indicates the potential for shallow groundwater resulting from soil drainage capacity, geology, and hydrology. 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 develop-ment at all locations in the Copperton quadrangle. Site-specific geotechnical/geologic-hazard investigations can resolve uncertainties inherent in generalized hazard mapping and help ensure safety by identifying the need for special engineering design, mitigation, and/or construction techniques. These investigations are particularly important for areas within the Copperton 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. 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. Site-specific geotechnical/ geologic-hazard 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.

For additional information about the shallow groundwater potential in the Copperton quadrangle, refer to the accompanying report.



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SCALE 1:24,000

1 0.5 0 1 MILE

5000 2500 0 5000 FEET

1 0.5 0 1 KILOMETER

CONTOUR INTERVAL 20 FEET

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UTAH

QUADRANGLE LOCATION

11°50'
TRUE NORTH
MAGNETIC NORTH

APPROXIMATE MEAN DECLINATION, 2014

LIQUEFACTION SUSCEPTIBILITY MAP OF THE COPPERTON QUADRANGLE, SALT LAKE COUNTY, UTAH

by

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

2014

1	2	3
4		5
6	7	8

1. Farnsworth Peak
2. Magna
3. Salt Lake City South
4. Bingham Canyon
5. Midvale
6. Lowe Peak
7. Tickville Spring
8. Jordan Narrows

ADJOINING 7.5' QUADRANGLE NAMES

ISBN 978-1557918994

EXPLANATION

Not Mapped – Area not mapped due to significant and ongoing human disturbance.

LIQUEFACTION SUSCEPTIBILTY CATEGORIES

High – 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.

Moderate – 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.

Low – Geologic units that consist of moderately to poorly sorted sands and gravels depth to groundwater is likely greater than or equal to 50 feet (15 m) below the ground surface. These locations have been identified by shallow groundwater potential mapping as likely to develop perched groundwater conditions due to soil drainage properties or confining geologic units, which may contribute to increased liquefaction potential.

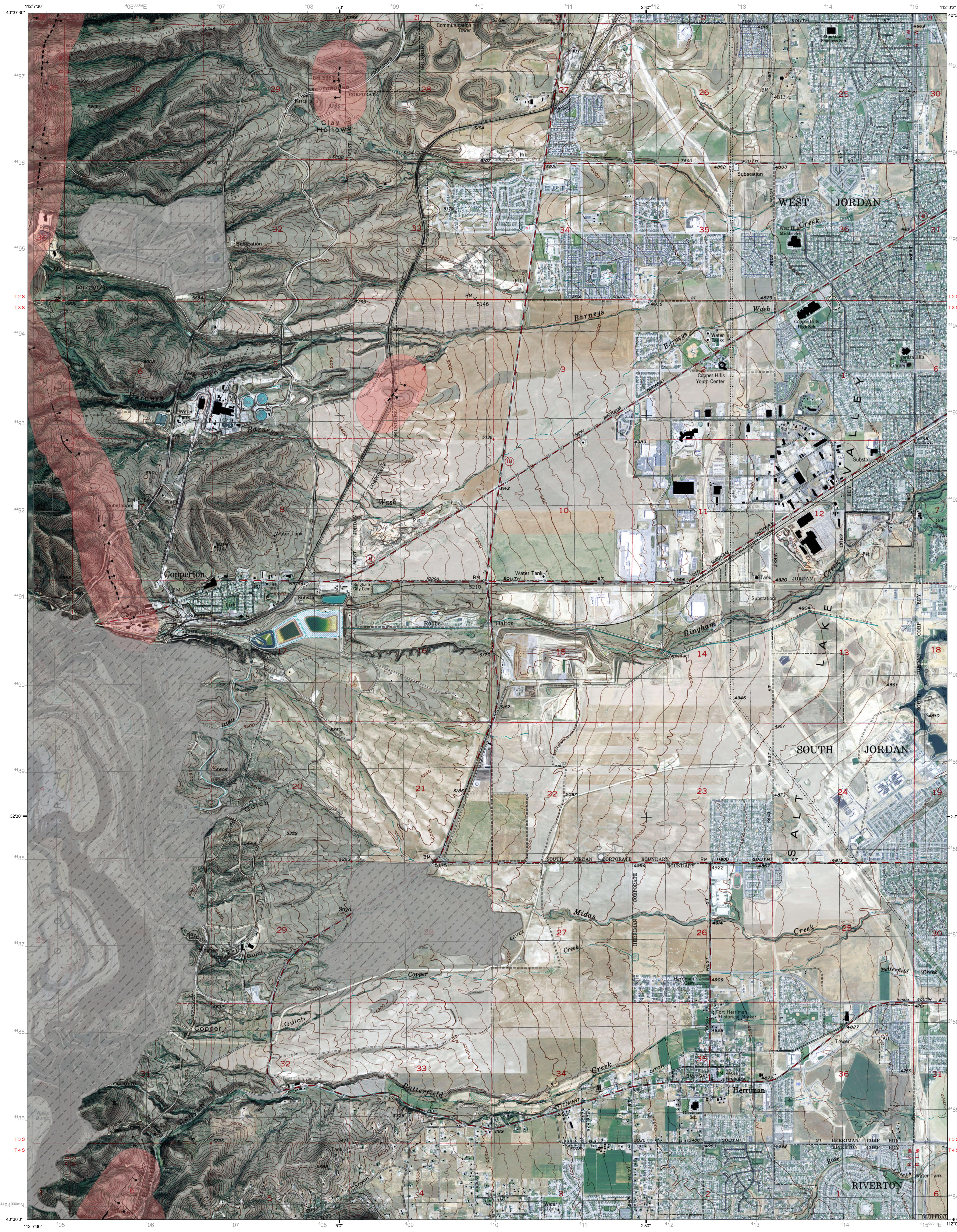
Very Low – Geologic units that consist of poorly sorted sands and gravels where depth to groundwater is greater than 50 feet (15 m). Liquefaction susceptibility is considered very low in these units because of their textural characteristics, age, and/or degree of cementation.

Not Susceptible – Bedrock units not susceptible to liquefaction.

USING THIS MAP

This map shows areas of liquefaction susceptibility in the Copperton quadrangle. The map is intended for general planning purposes to indicate where liquefaction susceptibility may exist and to assist in the design of liquefaction-hazard investigations. 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. This map 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 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.

For land-use planning recommendations relative to the different susceptibility categories as well as additional information about liquefaction hazard in the Copperton quadrangle, refer to the accompanying report.



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SCALE 1:24,000

1 0.5 0 1 MILE

5000 2500 0 5000 FEET

1 0.5 0 1 KILOMETER

CONTOUR INTERVAL 20 FEET

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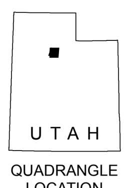
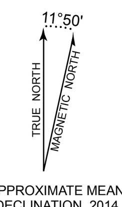
Datum: NAD 1983
Spheroid: Clarke 1886

GIS and Cartography: Jessica J. Castleton and Ben A. Erickson



QUADRANGLE LOCATION



APPROXIMATE MEAN DECLINATION, 2014

SURFACE FAULT RUPTURE HAZARD MAP OF THE COPPERTON QUADRANGLE, SALT LAKE COUNTY, UTAH

by

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

2014

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8. Jordan Narrows

ADJOINING 7.5' QUADRANGLE NAMES

ISBN 978-1557918994

EXPLANATION

Not Mapped – Area not mapped due to significant and ongoing human disturbance.

SURFACE FAULT RUPTURE HAZARD CATEGORIES

Well-located fault – bar and ball on downdropped side: Surface-fault-rupture hazard investigations recommended for all structures intended for human occupancy and all critical facilities.

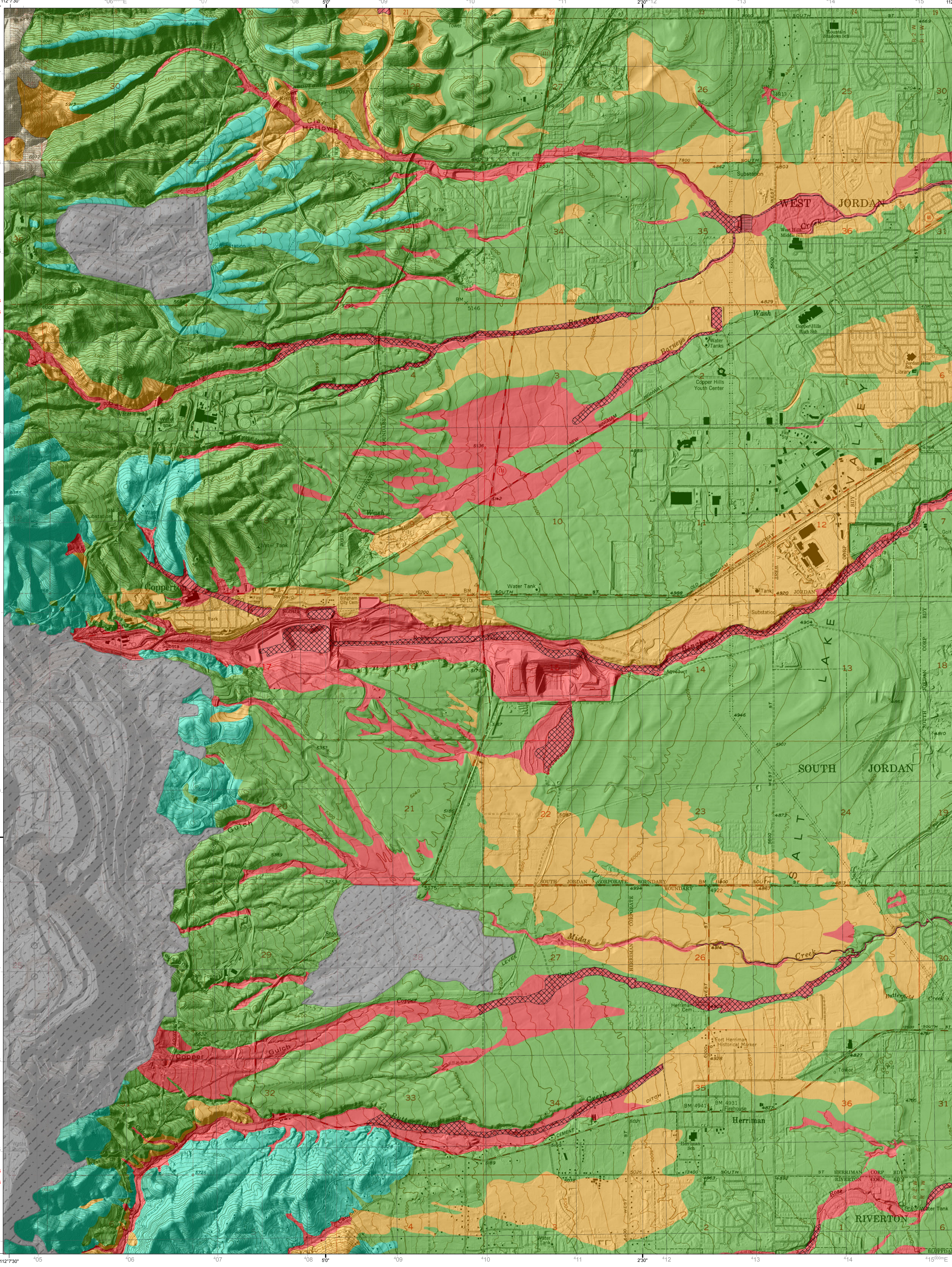
Approximately located or concealed fault with an unknown activity class – bar and ball on downdropped side: Activity class unknown; paleoseismic data are lacking; dashed where approximately located, dotted where concealed and approximately located. The UGS recommends investigators consider all possible Quaternary faults to be Holocene unless data are adequate to preclude Holocene displacement; preliminary investigations should be conducted to make this determination. If the fault is determined to be Holocene investigations should be conducted according to that activity class (Christenson and others, 2003). If the fault is determined not to be Holocene in preliminary investigations, but is determined to be a Quaternary fault then surface-fault-rupture hazard investigations are recommended for all essential and critical facilities. Investigations for other structures intended for human occupancy are optional (but recommended) because of the low likelihood of surface fault rupture, although surface fault rupture is still possible.

Surface-fault-rupture hazard special-study area – bar and ball on downdropped side: Because the location of the faults on the Copperton quadrangle are approximate and in places concealed by younger deposits, the special-study areas around the faults extend 1000 feet on each side of the mapped fault trace (in accordance with Christenson and others, 2003).

USING THIS MAP

This map shows potentially active faults on the Copperton quadrangle along which surface faulting may occur. A special-study area is shown around each fault, within which the UGS recommends a site-specific, surface-fault-rupture hazard investigation 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. This map is not intended for use at scales other than 1:24,000; it is our opinion that the inventory of potentially active faults shown on this map is likely complete at this scale. However, smaller faults may not have been detected during mapping or are 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 as well as other faults and fault-related features not evident at 1:24,000-scale.

For additional information about the surface-fault-rupture hazard in the Copperton quadrangle, refer to the accompanying report.



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1 0.5 0 1 MILE

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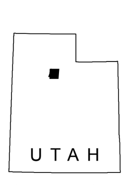
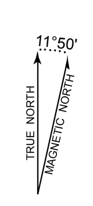


QUADRANGLE LOCATION



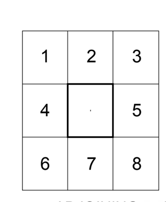
APPROXIMATE MEAN DECLINATION, 2014

FLOOD HAZARD MAP OF THE COPPERTON QUADRANGLE, SALT LAKE COUNTY, UTAH

by

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

2014



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ADJOINING 7.5' QUADRANGLE NAMES

ISBN 978-1557918994

EXPLANATION

Not Mapped – Area not mapped due to significant and ongoing human disturbance.

Bedrock – Area of bedrock in the Oquirrh Mountains that do not pose a flooding hazard but may contribute as a source area.

FEDERAL EMERGENCY MANAGEMENT AGENCY (FEMA) FLOOD INSURANCE RATE MAP (FIRM) ZONES

Zone A – Area having a 1% annual chance of flooding (100-year flood) and a 26% chance of flooding over the life of a 30-year mortgage. Flood event generally determined using approximate methodologies. Mandatory flood insurance purchase requirements and floodplain management standards apply. Base flood elevations are not determined.

Zone AE – Area of special flood hazard zone with the same specifications as Zone A, however base flood elevations are determined.

Zone X 0.2% – Areas having a 0.2% annual chance of flooding (500-year flood), or 1% annual chance of flooding (100-year flood) with average depths of less than 1 foot (0.3 m) or having a drainage areas less than 1 square mile (2.6 square km), and areas protected by levees from 100-year flood.

All areas ouside of zone A, AE, and X determined to be outside the 0.2% annual chance floodplain.

FLOOD HAZARD CATEGORIES

High – Active floodplains and low terraces along perennial and larger ephemeral streams, active alluvial fans, and deposits that periodically flood due to shallow ground water and streamflow.

Moderate – Stream channels, floodplains, 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.

Low – Minor ephemeral drainages, subject to infrequent flooding from adjacent upland areas during cloudburst storms.

Very Low – Pediment-mantle alluvium on ridge tops.

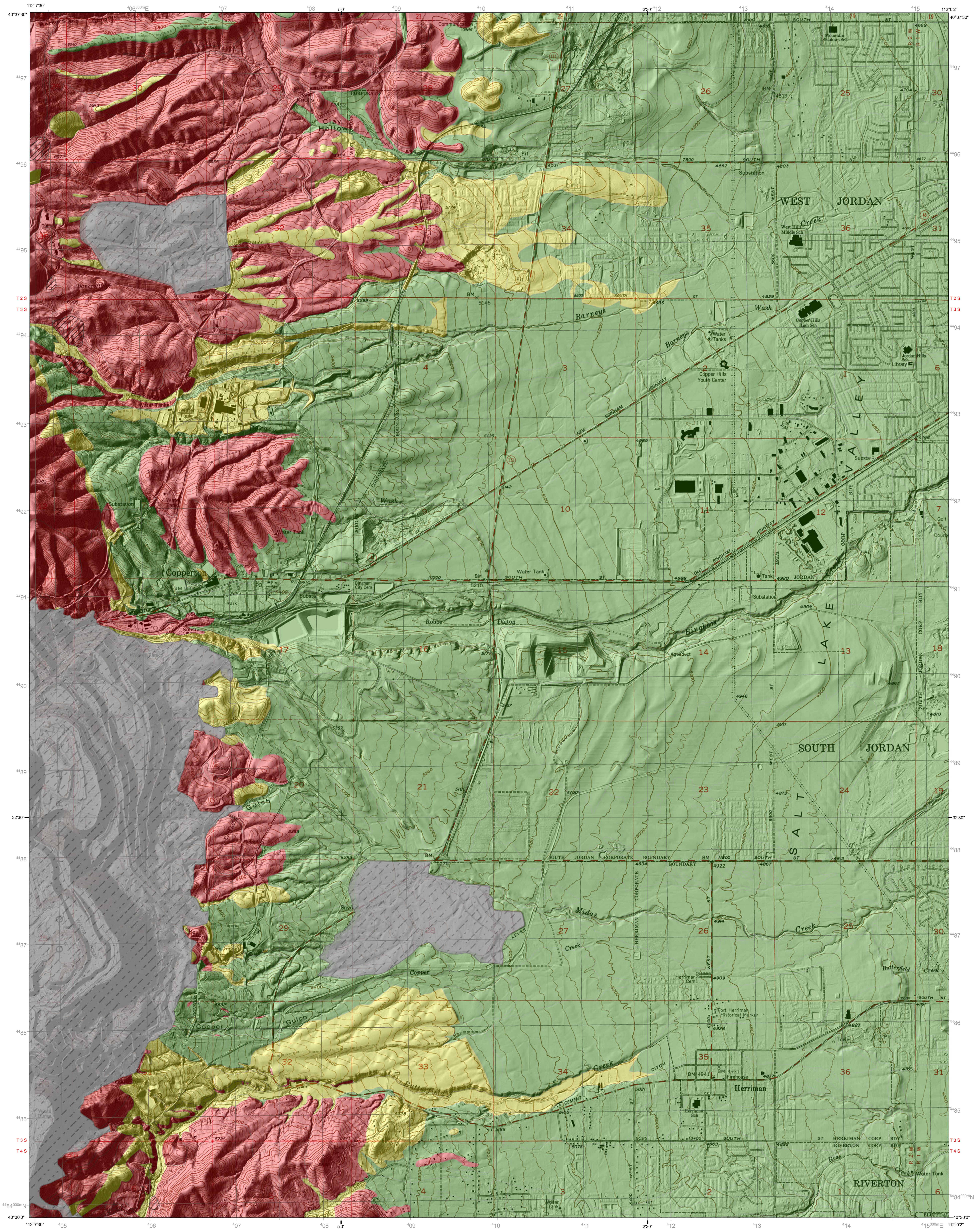
USING THIS MAP

This map shows drainages covered by the 2009 Flood Insurance Rate Maps (FIRMs) 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. This map is designed for use in general planning to indicate the need for site-specific investigations and identify areas where the FIRM can be consulted to determine the availability of flood insurance. This map also shows where existing developments are within potential flood-hazard areas and therefore may require remedial flood-hazard-reduction measures.

This map 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. This map 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.

For additional information about the flood hazard in the Copperton quadrangle, refer to the accompanying report.

UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources



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MAGNETIC NORTH

APPROXIMATE MEAN DECLINATION, 2014

LANDSLIDE SUSCEPTIBILITY MAP OF THE COPPERTON QUADRANGLE, SALT LAKE COUNTY, UTAH

by

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

2014

1	2	3
4		5
6	7	8

1. Farnsworth Peak
2. Magna
3. Salt Lake City South
4. Bingham Canyon
5. Midvale
6. Lowe Peak
7. Tickville Spring
8. Jordan Narrows

ADJOINING 7.5' QUADRANGLE NAMES

ISBN 978-1557918994

EXPLANATION

Not Mapped – Area not mapped due to significant and ongoing human disturbance.

Landslide Deposit – As mapped by Biek and others (2007) and identified by this study.

LANDSLIDE HAZARD CATEGORIES

High – Area identified in field observations, aerial photography analysis, geologic maps, and topographic maps as highly susceptible to future landslide movement, due to slope angle, geologic deposit, and existing landslides within the geologic unit. A critical angle of 10 degrees was assigned for Lake Bonneville and Tertiary volcanic deposits, and 20 degrees for Oquirrh Group deposits.

Moderate – Area identified in field observations, aerial photography analysis, geologic maps, and topographic maps as moderatly susceptible to future landslide movement as defined by areas having slopes below the assigned critical angle in geologic units highly susceptible to landslideing and Quaternary deposits overlaying these units.

Low – Area identified as low landslide susceptibility as defined by areas having slopes below the critical angle in geologic units unlikely to be susceptible to landsliding.

USING THIS MAP

This map shows areas of relative landslide susceptibility and indicates where site-specific slope-stability conditions (material strength, orientation of bedding and/or fractures, groundwater conditions, erosion or undercutting) should be evaluated prior to development. The mapped boundaries between landslide-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. The landslide-susceptibility categories do not consider hazards caused by cuts, fills, or other alterations to the natural terrain.

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 landslide-susceptibility information and should be conducted by qualified professionals. Mapped landslide susceptibilities indicate only the source zones of landslides (the parts of slopes that may fail). This map does not show how far downslope the materials may travel before stopping. Proposed development in areas downslope of landslide source zones should consider this in site-specific investigations. A valid landslide-hazard evaluation must address all pertinent conditions that could affect, or be affected by, the proposed development, including earthquake ground shaking.

For additional information about landslides and landslide susceptibility in the Copperton quadrangle, refer to the accompanying report.

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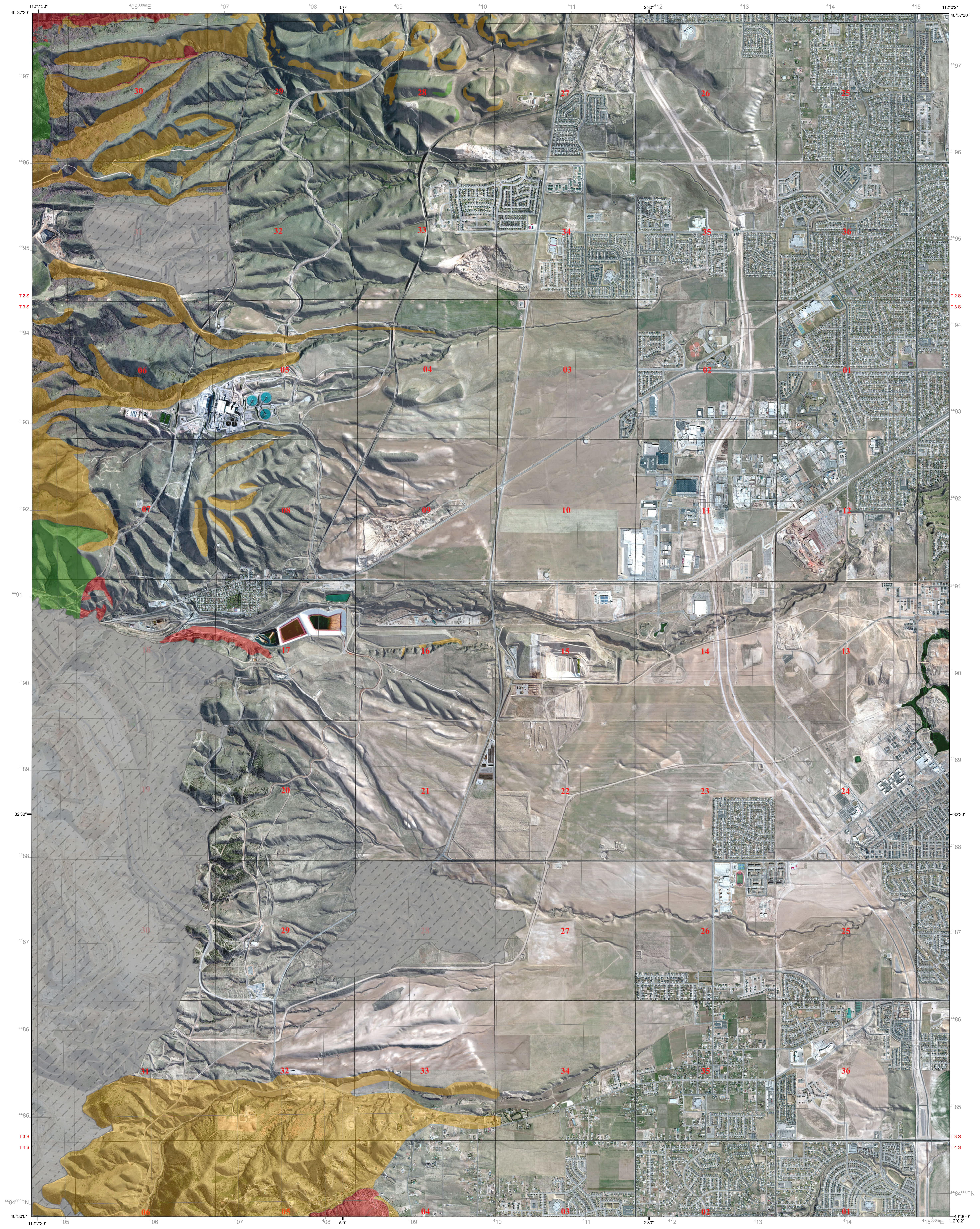

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SCALE 1:24,000

1 0.5 0 1 MILE

5000 2500 0 5000 FEET

1 0.5 0 1 KILOMETER

CONTOUR INTERVAL 20 FEET

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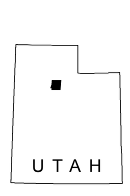
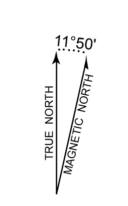
Datum: NAD 1983
Spheroid: Clarke 1886

GIS and Cartography: Jessica J. Castleton and Ben A. Erickson



QUADRANGLE LOCATION



APPROXIMATE MEAN DECLINATION, 2014

ROCK-FALL HAZARD MAP OF THE COPPERTON QUADRANGLE, SALT LAKE COUNTY, UTAH

by

Jessica J. Castleton and Greg N. McDonald

2014

Utah Geological Survey
1594 West North Temple, Suite 3110
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6. Lowe Peak
7. Tickville Spring
8. Jordan Narrows

ADJOINING 7.5' QUADRANGLE NAMES

ISBN 978-1557918994
9 781557 918994

EXPLANATION

Not Mapped – Area not mapped due to significant and ongoing human disturbance.

ROCK-FALL HAZARD CATEGORIES

High – Slopes that are greater than or equal to 20 degrees within a geologic unit highly susceptible to rock fall, and slopes greater than 35 degrees within a rock-fall source area within a geologic unit moderately susceptible to rock fall. High-hazard areas include rock-fall sources and their associated shadow angle zones.

Moderate – Slopes between 20 and 35 degrees within a geologic unit moderately susceptible to rock fall, and slopes greater than 35 degrees within a rock-fall source area within a geologic unit having low susceptibility to rock fall. Moderate-hazard areas include rock-fall sources and their associated shadows, which extend into rock-fall source areas that would otherwise be mapped in the low-hazard category.

Low – Slopes between 20 and 35 degrees within a geologic unit having low susceptibility to rock fall. Low-hazard areas include rock-fall sources and their associated shadows, which extend into areas that would otherwise be mapped as having a negligible hazard.

Rock-fall hazard is considered negligible in the remainder of the study area if not included in one of the above hazard categories.

USING THIS MAP

This map shows areas of relative rock-fall hazard in the Copperton quadrangle. We recommend performing site-specific geotechnical/geologic-hazard investigations within the mapped rock-fall hazard areas. 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, site-specific assessment 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. This map is based on limited geologic and slope data, and aerial photography analysis. The quality of the map depends on the quality of these data, which varies 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 due to 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 rock-fall-hazard categories do not consider hazards caused by cuts, fills, or other alterations to the natural terrain. This map is intended primarily for planning purposes and should not be used as a substitute 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.

For additional information about the rock-fall hazard in the Copperton quadrangle, refer to the accompanying report.

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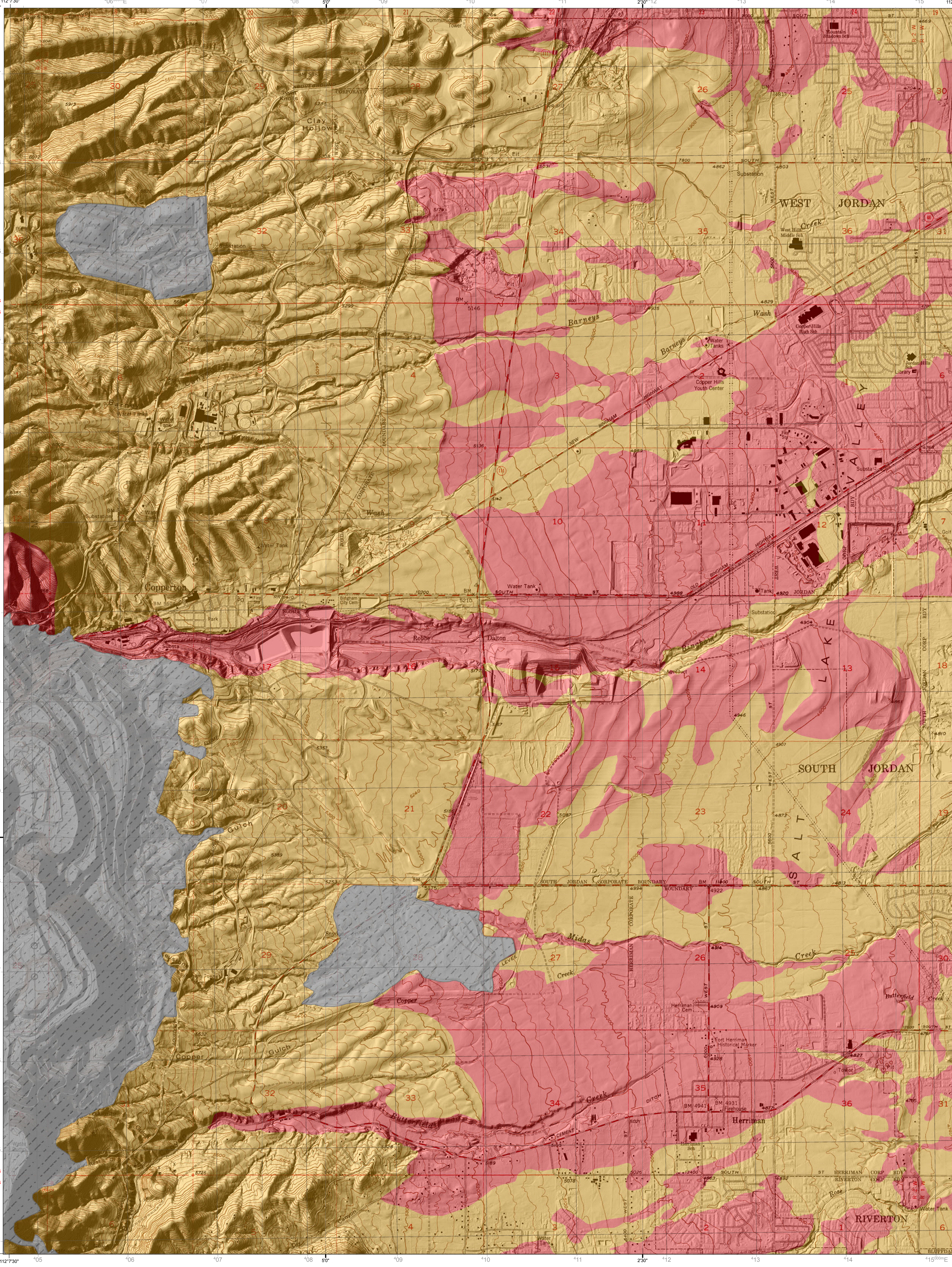

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SCALE 1:24,000

1 0.5 0 1 MILE

5000 2500 0 5000 FEET

1 0.5 0 1 KILOMETER

CONTOUR INTERVAL 20 FEET

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GIS and Cartography: Jessica J. Castleton and Ben A. Erickson

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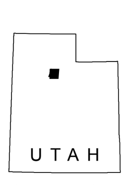

QUADRANGLE LOCATION

APPROXIMATE MEAN DECLINATION, 2014

RADON HAZARD POTENTIAL MAP OF THE COPPERTON QUADRANGLE, SALT LAKE COUNTY, UTAH

by

Jessica J. Castleton and Greg N. McDonald

2014

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ADJOINING 7.5' QUADRANGLE NAMES

ISBN 978-1557918994

EXPLANATION

Not Mapped – Area not mapped due to significant and ongoing human disturbance.

INDOOR RADON HAZARD POTENTIAL CATEGORIES

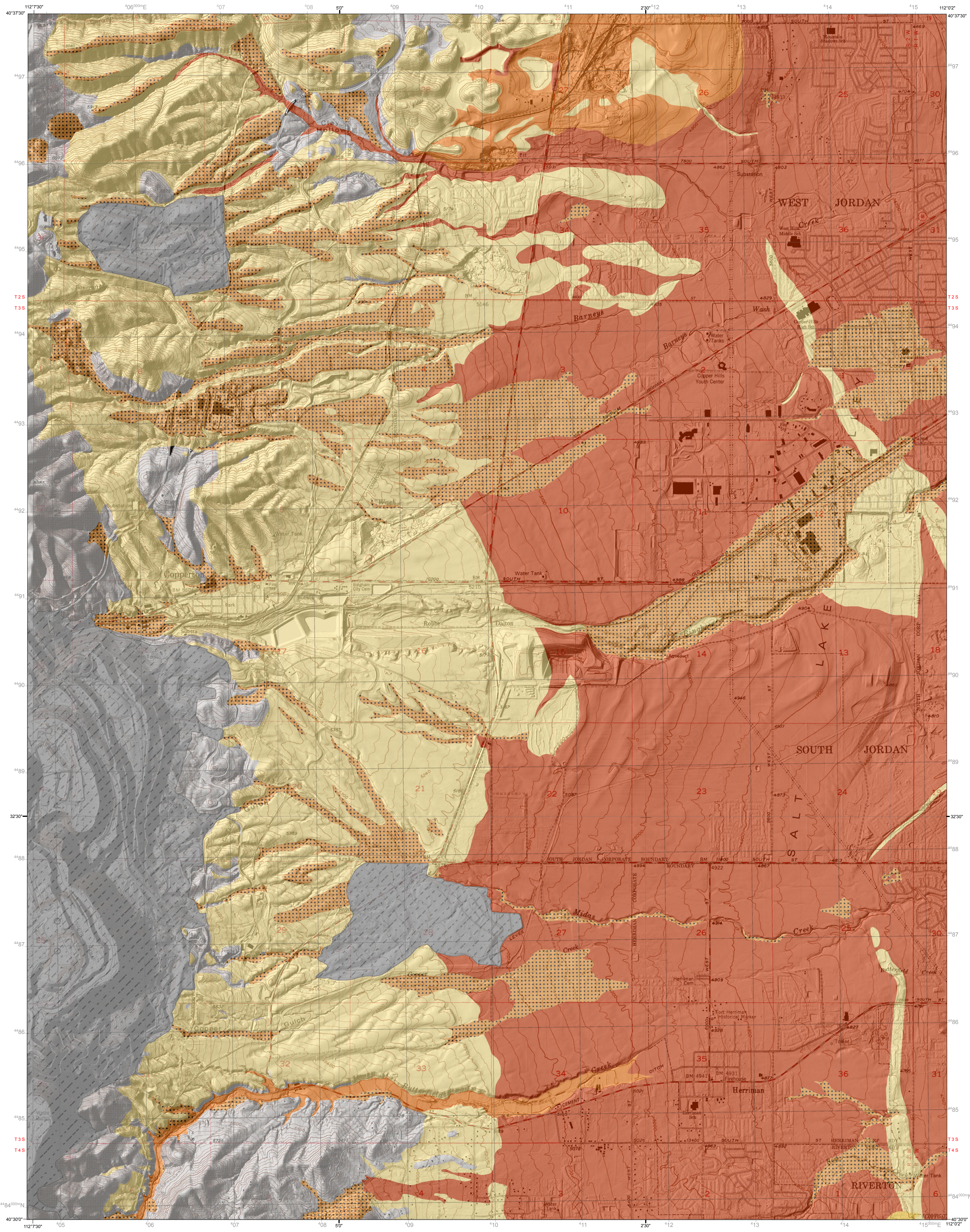
High – Area where probable soil uranium concentrations are greater than 3 parts per million (ppm); groundwater depth is greater than 30 feet below the surface and soil is highly permeable to moderately permeable.

Moderate – Area where probable soil uranium concentrations range from 2–3 ppm; ground water depth is less than 30 feet below the surface and soil is moderately permeable.

USING THIS MAP

This map is intended to provide an estimate of the underlying geologic conditions that may contribute to the indoor-radon-hazard potential. This map is not intended to indicate indoor radon levels in specific buildings. Although certain geologic factors are conducive to elevated indoor radon hazard potential, other highly variable factors affect indoor radon levels, such as building materials and foundation openings; therefore, indoor radon levels can vary greatly between structures located in the same hazard category. 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 indoor-radon-level testing. Indoor radon testing is important in all hazard categories and we recommend testing be completed in all existing structures.

For additional information about the indoor radon potential in the Copperton quadrangle, refer to the accompanying report.



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1 0.5 0 1 MILE

5000 2500 0 5000 FEET

1 0.5 0 1 KILOMETER

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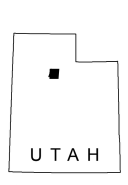
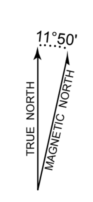


QUADRANGLE LOCATION



APPROXIMATE MEAN DECLINATION, 2014

COLLAPSIBLE SOIL SUSCEPTIBILITY MAP OF THE COPPERTON QUADRANGLE, SALT LAKE COUNTY, UTAH

by

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

2014

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ADJOINING 7.5' QUADRANGLE NAMES

ISBN 978-1-55791-899-4

EXPLANATION

Not Mapped – Area not mapped due to significant and ongoing human disturbance.

COLLAPSIBLE SOIL SUSCEPTIBILITY CATEGORIES

Highly Collapsible Soil – Unconsolidated geologic units containing highly collapsible soils with reported collapse values greater than or equal to 5 percent.

Collapsible Soil A – Unconsolidated geologic units having reported collapse values between 3 and 5 percent. In areas continually subjected to saturation or flooding, collapsible soils are unlikely.

Collapsible Soil B – Unconsolidated geologic units lacking geotechnical collapse data, but for which other geotechnical information (chiefly low unit weight and moisture content) are indicative of materials susceptible to collapse. In areas continually subjected to saturation or flooding, collapsible soils are unlikely.

Collapsible Soil C – Unconsolidated, young geologic units (Holocene) for which no geotechnical data are available, but which have a genesis or texture susceptible to collapse. In areas continually subjected to saturation or flooding, collapsible soils are unlikely.

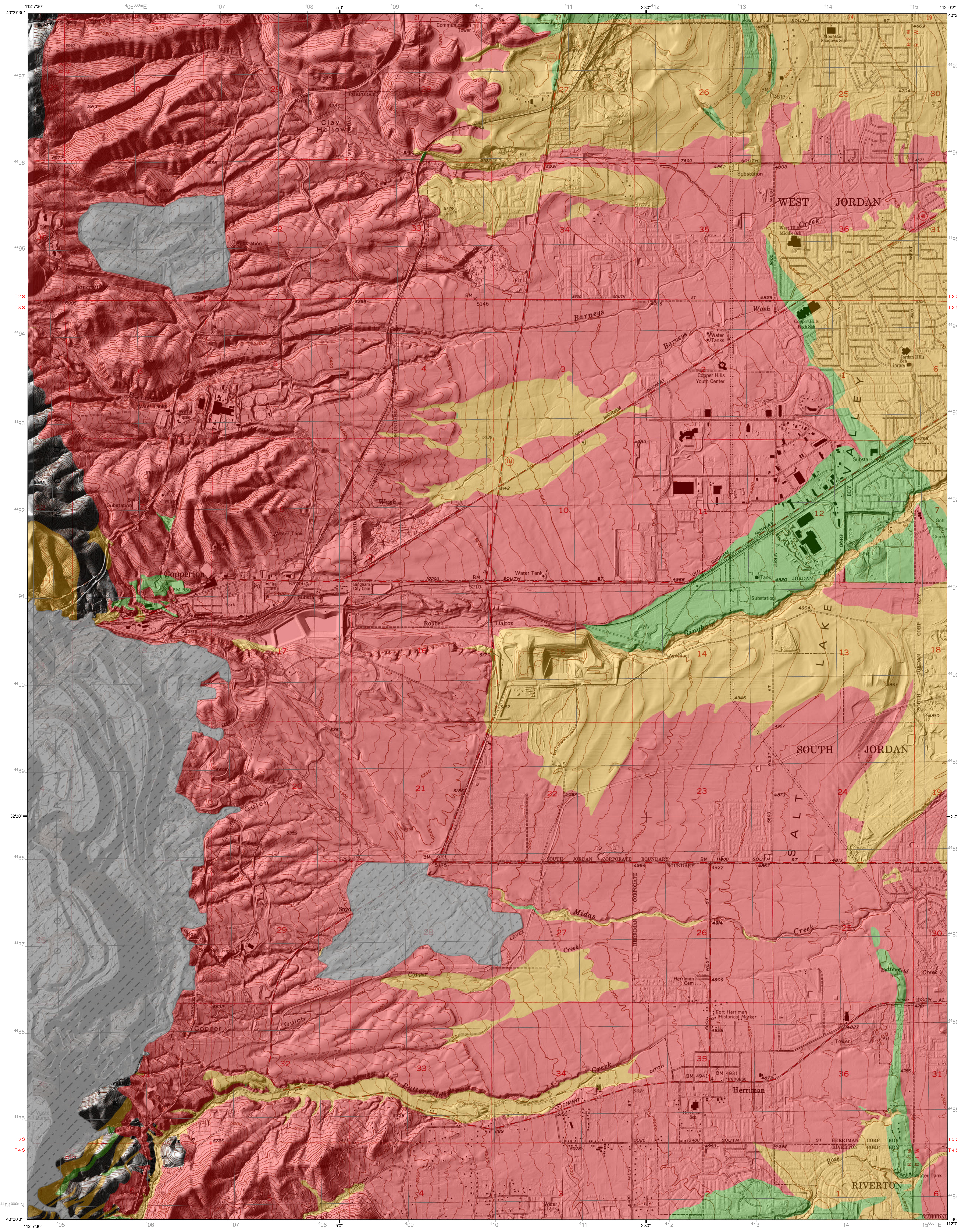
Collapsible Soil D – Unconsolidated older geologic units (Pleistocene) for which no geotechnical data are available, but which have a genesis or texture susceptible to collapse. Because of their age, these deposits have experienced greater exposure to natural wetting and may have already experienced collapse, and/or the deposits may have become cemented by secondary calcium carbonate or other soluble minerals, making them less susceptible to collapse.

Bedrock – Area unlikely to be susceptible to collapse.

USING THIS MAP

This map shows the location of known and suspected collapsible soil conditions in the Copperton 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 Copperton 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, mitigation, and/or construction techniques. 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 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.

For additional information about collapsible soil susceptibility in the Copperton quadrangle, refer to the accompanying report.



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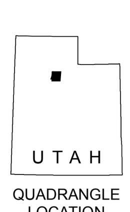
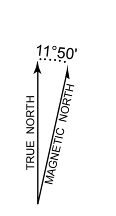


QUADRANGLE LOCATION



APPROXIMATE MEAN DECLINATION, 2014

EXPANSIVE SOIL AND ROCK SUSCEPTIBILITY MAP OF THE COPPERTON QUADRANGLE, SALT LAKE COUNTY, UTAH

by

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

2014

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ADJOINING 7.5' QUADRANGLE NAMES

EXPLANATION

Not Mapped – Area not mapped due to significant and ongoing human disturbance.

EXPANSIVE SOIL SUSCEPTIBILITY

High – Soil or rock classified by the U.S. Natural Resources Conservation Service (NRCS) as having a high potential for volumetric change (linear extensibility greater than 6%); includes geologic units mapped by Biek and others (2007) in which geotechnical testing indicates an abundance of expansive clay minerals (swell/collapse test [SCT] values greater than or equal to 3% and/or liquid limit [LL] values greater than or equal to 45, and plasticity index [PI] values greater than or equal to 20). Includes geologic bedrock units mapped by Biek and others (2007) that weather to clay.

Moderate – Soil or rock classified by the NRCS as having moderate susceptibility for volumetric change (linear extensibility 3–6%); includes interbedded Lake Bonneville deposits mapped by Biek and others (2007) in which geotechnical borehole logs indicate thick expansive clay layers are present. Typically, these units have SCT values of 2–3% and/or an LL of 20–40 and a PI of 10–30. Includes geologic bedrock units mapped by Biek and others (2007) that weather to clay.

Low – Soil or rock classified by the NRCS as having low potential for volumetric change (linear extensibility 0–3%); includes geologic units dominated by sand and gravel mapped by Biek and others (2007) in which geotechnical testing indicates a lack of expansive clay minerals (SCT values of 0–2% and/or an LL of 0–30 and a PI of 0–15).

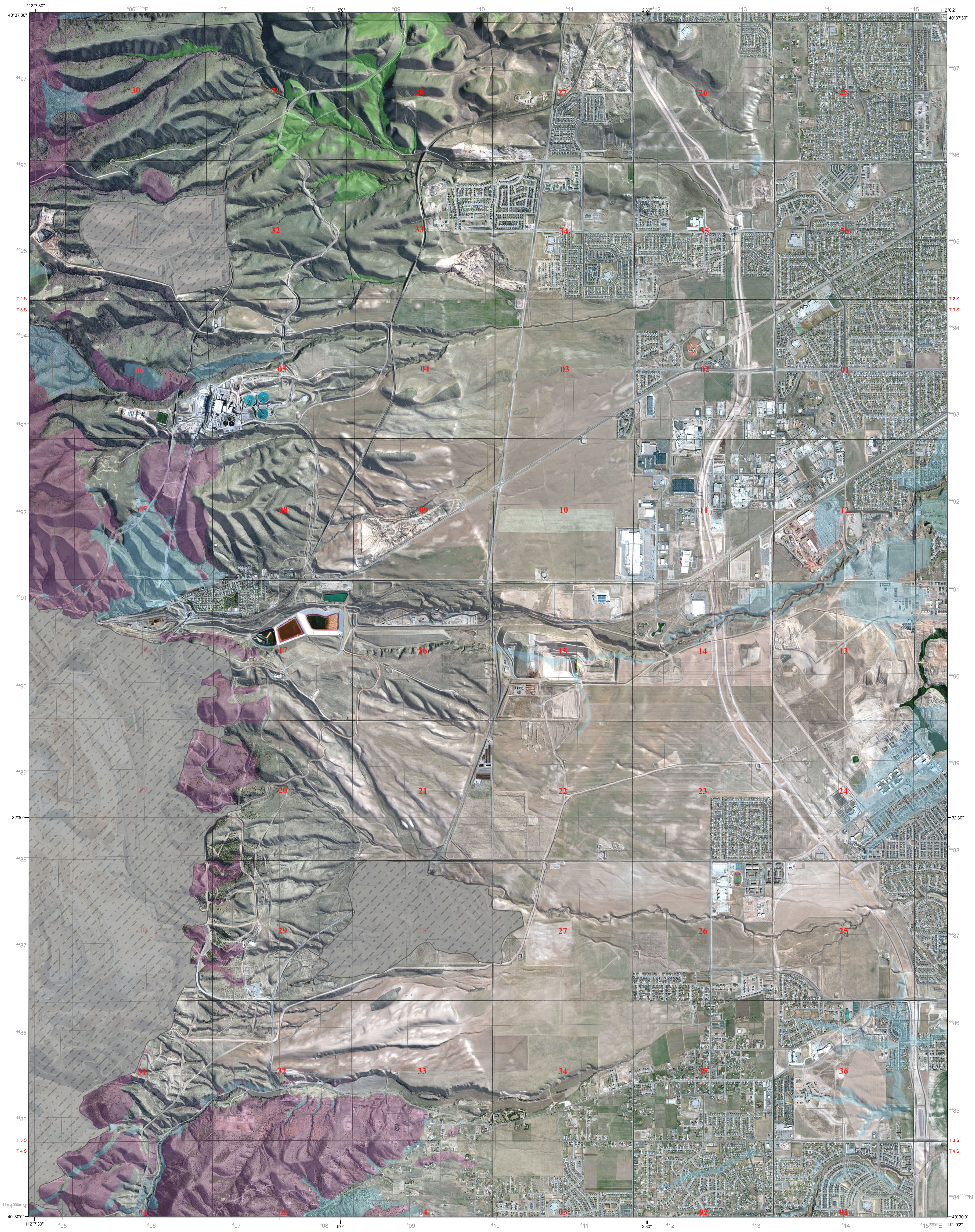
Area having no expansive soil or rock.

USING THE MAP

This map shows the location of known or suspected expansive soil and rock in the Copperton quadrangle. The presence and severity of expansive soil or rock along with other geologic hazards should be addressed in site-specific geotechnical/geologic-hazard investigations. 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. 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, mitigation and/or construction techniques.

For additional information about expansive soil and rock in the Copperton quadrangle, refer to the accompanying report.

ISBN 978-1-55791-899-4



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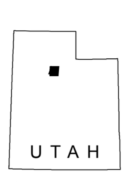
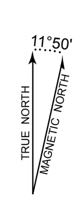


QUADRANGLE LOCATION



APPROXIMATE MEAN DECLINATION, 2014

SHALLOW BEDROCK POTENTIAL MAP OF THE COPPERTON QUADRANGLE, SALT LAKE COUNTY, UTAH

by

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

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ISBN 978-1557918994

EXPLANATION

Not Mapped – Area not mapped due to significant and ongoing human disturbance.

SHALLOW BEDROCK CATEGORIES

Hard – Area where generally hard and resistant (when unweathered) bedrock crops out at the ground surface as identified by Biek and others (2007). Bedrock units in this category typically require blasting to excavate; includes bedrock units older than Tertiary age.

Soft – Area where the less resistant Jordan Narrows unit of the Tertiary Salt Lake Formation crops out at the ground surface as identified by Biek and others (2007). Even where unweathered, bedrock can be excavated without blasting, although local blasting may be required. The Jordan Narrows unit contains expansive clay minerals and can be deeply weathered.

Buried – Area where depth to bedrock is greater than or equal to 10 feet (3 m) beneath soil cover.

Deep – Area where depth to bedrock is greater than 10 feet (3 m).

USING THIS MAP

This map shows locations where bedrock crops out at the ground surface or is present in the shallow subsurface in the Copperton quadrangle. The map is intended for general planning purposes to indicate where shallow bedrock conditions may exist and special investigations may be required. 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. 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, 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 recommendations should be provided.

For additional information about shallow bedrock in the Copperton quadrangle, refer to the accompanying report.