GEOLOGIC HAZARDS OF THE STATE ROUTE 9 CORRIDOR, LA VERKIN CITY TO TOWN OF SPRINGDALE, WASHINGTON COUNTY, UTAH

by Tyler R. Knudsen and William R. Lund

SPECIAL STUDY 148
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Cover photo: *The Watchman landslide in Springdale, Utah, developed in the spring of 2005 and is one of several historically active landslides in the State Route 9 Corridor Geologic-Hazard Study Area.*

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GEOLOGIC HAZARDS OF THE STATE ROUTE 9 CORRIDOR, LA VERKIN CITY TO TOWN OF SPRINGDALE, WASHINGTON COUNTY, UTAH

by Tyler R. Knudsen and William R. Lund

ABSTRACT

Historically, the communities of La Verkin, Virgin, Rockville, and Springdale have been affected by a variety of geologic hazards. The 1992 St. George earthquake, recent damaging rock falls, riverine floods most recently in 2005 and 2010, recurrent flash floods and landslides, and problems associated with collapsible soil and expansive soil and rock demonstrate that the communities are vulnerable to geologic hazards, and that public officials require reliable hazard information as they plan for and manage future growth. The purpose of this study is to provide municipal, county, and regional administrative, safety, and planning officials, as well as consultants, landowners, and others with geographic information system (GIS)-based information on the kinds and locations of geologic hazards that may affect existing and future development in the State Route 9 Corridor Geologic-Hazard Study Area (SR-9 study area). The SR-9 study area encompasses 97 square miles, and consists of a corridor ranging from about 2 to 8 miles wide and 15 miles long centered on SR-9, that extends from the western edge of the Virgin 7.5-minute quadrangle in La Verkin City to the Town of Springdale's eastern boundary with Zion National Park.

This report includes nine 1:24,000-scale (1" = 2000') geologic-hazard maps that cover flooding and debris flows, rock fall, landslides, surface faulting, liquefaction, collapsible soil, expansive soil and rock, gypsiferous soil and rock, soil piping, erosion, and wind-blown sand. Available geotechnical data are insufficient to prepare an earthquake-site-conditions map; therefore, information on the ground-shaking hazard in the study area is discussed in a section in this report rather than shown on a map. Each geologic-hazard map is a stand-alone document that provides information on the data sources and techniques used to create the map, the nature and distribution of the hazard, and possible hazard-reduction measures. The study includes an ArcGIS 10.0 file geodatabase that contains all of the information used to develop the hazard maps. This geodatabase may be used directly in ArcGIS 10.0 or later versions, or in other GIS applications.

The maps are intended for use in general planning to indicate where site-specific geotechnical and geologic-hazard investigations are necessary. We recommend a site-specific geotechnical investigation for all new construction in the study area, and a geologic assessment to identify potential geologic hazards at sites within special-study areas shown on the maps accompanying this report. Site-specific investigations can resolve uncertainties inherent in these 1:24,000-scale maps, and help increase safety by identifying the need for special construction design or hazard mitigation.

Because of their wide distribution, frequent occurrence, and destructive potential, we expect floods, rock falls, landslides, collapsible soil, and expansive soil and rock to be the principal geologic hazards that will affect the SR-9 study area in the future. With the exception of the effects of a rare but potentially catastrophic large earthquake, the remaining geologic hazards considered in this study are typically localized, and while potentially costly when not recognized and properly accommodated for in project planning, design, and maintenance, the problems associated with them are rarely life threatening.

INTRODUCTION

Purpose

The purpose of this study is to provide municipal, county, and regional administrative and planning officials, as well as consultants, landowners, and others with GIS-based information on the kinds and locations of geologic hazards that may affect existing and future development in the State Route 9 Corridor Geologic-Hazard Study Area (SR-9 study area) (table 1, figure 1). Three of the four principal communities within the study area (La Verkin, Virgin, Rockville, and Springdale) have experienced significant growth over the past decade, and are expected to experience continued growth in the future (table 2). Additionally, SR-9 is an important transportation corridor that conveys many of the more than 2.5 million annual visitors to Zion National Park (National Park Service, 2011), which is adjacent to the study area on the north and east (figure 1), and was the subject of an earlier Utah Geological Survey (UGS) geologic-hazard investigation (Lund and others, 2010).

The principal products of this study are nine 1:24,000-scale

Table 1. *Principal geologic hazards in the State Route 9 Corridor Geologic-Hazard Study Area.*

Flooding and debris flows
Landslides
Rock fall
Collapsible soil
Expansive soil and rock
Gypsiferous soil and rockv
Surface faulting
Liquefaction
Soil piping, erosion, and wind-blown sand
Earthquake ground shaking[1]

[1]*Discussed in report only, data are insufficient to prepare an earthquake site conditions map.*

Table 2. *Census data and growth projections for communities in the State Route 9 Corridor Geologic-Hazard Study Area.*

Town	2000 Census[1]	2010 Census[2]	Percent Growth 2000–2010	2035 Projected Population[3]
La Verkin	3382	4060	20	24,012
Virgin	394	597	52	1463
Rockville	247	245	-1	689
Springdale	457	529	16	1726
Totals	4480	5431	21	27,890

[1]*U.S. Census Bureau (2000),* [2]*U.S. Census Bureau (2011),* [3]*Utah State University (2009)*

(1" = 2000') geologic-hazard maps covering the SR-9 study area (plates 1–9). Each map is a stand-alone document that provides details regarding a specific geologic hazard in the study area and hazard-mitigation recommendations. The maps are an aid for general planning to indicate where detailed, site-specific geotechnical and geologic-hazard investigations are required. The maps are not intended for use at scales larger than the scale at which they were compiled, and are not a substitute for site-specific investigations. Available geotechnical data are insufficient to prepare an earthquake-site-conditions map; therefore, information on the ground-shaking hazard in the SR-9 study area is discussed in a section in this report rather than shown on a map.

Regarding special studies, we recommend a site-specific geotechnical investigation for all new construction in the SR-9 study area, and a geologic assessment to identify potential geologic hazards at sites within special-study areas shown on the geologic-hazard maps. Site-specific investigations can resolve uncertainties inherent in these 1:24,000-scale maps, and help increase safety by identifying the need for special engineering design or hazard mitigation.

Background

Historically, the communities of La Verkin, Virgin, Rockville, and Springdale have been affected by a variety of geologic hazards (table 1). The 1992 St. George earthquake (M_L 5.8; Christenson, 1995), recent damaging rock falls (Knudsen, 2011; 2012), major riverine floods in 2005 and 2010, recurrent flash floods and landslides, and problems associated with collapsible soil and expansive soil and rock demonstrate that the communities are vulnerable to geologic hazards, and that public officials require reliable hazard information as they plan for and manage future growth.

The UGS previously conducted GIS-based geologic-hazard investigations of the rapidly urbanizing St. George–Hurricane metropolitan area (Lund and others, 2008b) and of high-visitation areas within Zion National Park (Lund and others, 2010; 2012). The scope and format of this investigation are closely based on those two previous geologic-hazard investigations.

The St. George–Hurricane study encompassed 366 square miles and includes the western part of La Verkin City. The Zion study encompassed 154 square miles within Zion National Park, and extends to the park's boundary with the Town of Springdale. The Town of Springdale municipal boundary locally extends into Zion National Park; geologic hazards in the portions of the town within the park were evaluated in the Lund and others (2010) study. The present study provides critical geologic-hazards information in the gap along SR-9 between the two previous studies (figure 2) that includes the eastern part of La Verkin City; the northern part of the Town of Apple Valley; the communities of Virgin, Rockville, and Springdale; and adjacent unincorporated areas of Washington County.

The Five County Association of Governments (FCAOG) was instrumental in obtaining funding for this study through the Utah Permanent Community Impact Fund Board. The communities in the study area also provided additional project funding. The UGS contributed a 50 percent in-kind match toward the cost of this project. The study area boundaries were established jointly by the UGS, the communities along the SR-9 corridor, and the FCAOG planning staff.

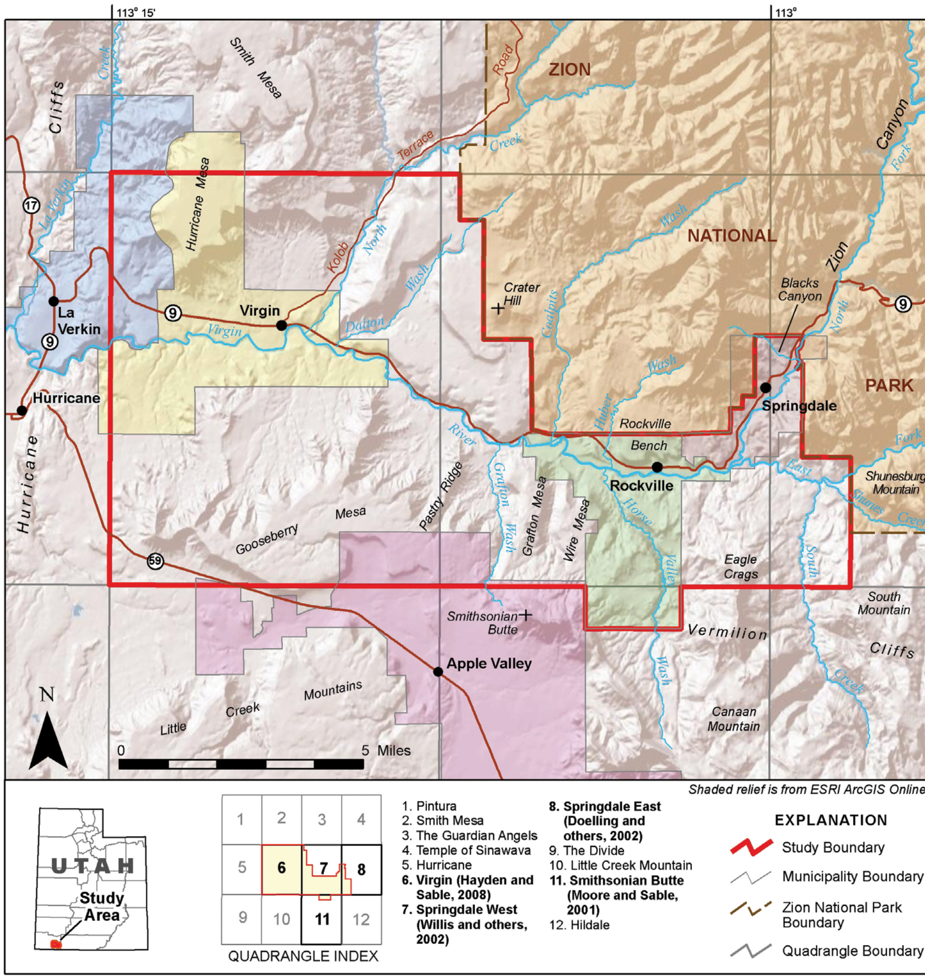

Figure 1. *Boundaries, principal developed areas, transportation corridors, index to U.S. Geological Survey 7.5' quadrangle maps, and UGS 7.5' geologic quadrangle maps (bold) in the State Route 9 Corridor Geologic-Hazard Study Area.*

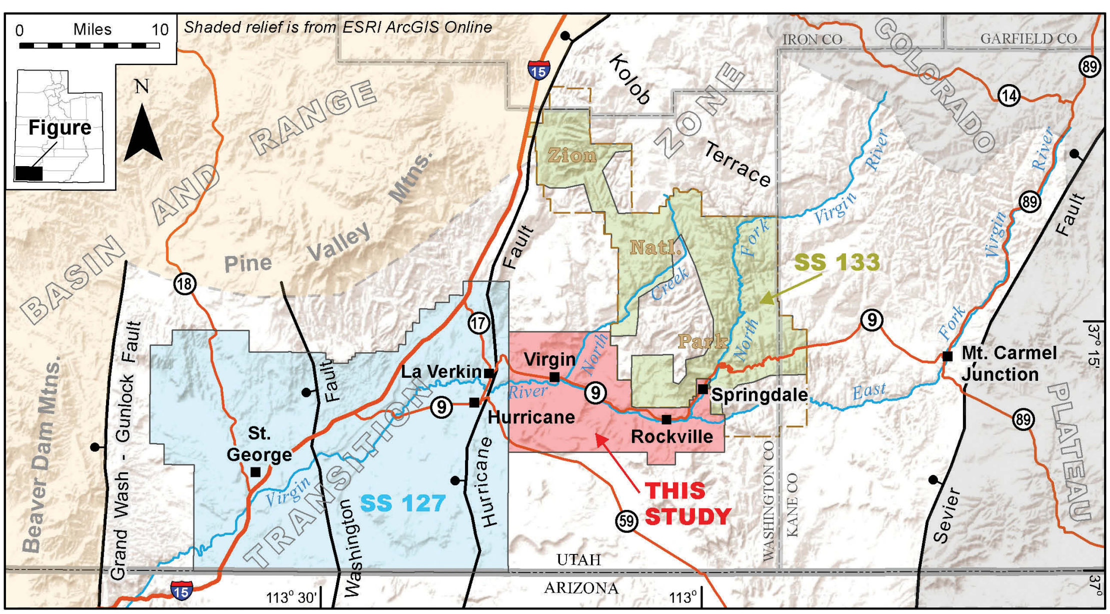

Figure 2. *Relation of the State Route 9 Corridor Geologic-Hazard Study Area to previous UGS geologic-hazard studies (Special Study 127 – Geologic Hazards and Adverse Construction Conditions, St. George–Hurricane Metropolitan Area, Washington County, Utah; Special Study 133 – Geologic Hazards of the Zion National Park Geologic-Hazard Study Area, Washington and Kane Counties, Utah), major transportation corridors, nearby communities, principal drainages, physiographic province boundaries, and large potentially active faults in the State Route 9 Corridor region.*

Scope of Work

The scope of work for this study consisted of:

(1) Identifying and reviewing digital geologic, hydrologic, and soils information; digital elevation models; and aerial photography available for the study area.

(2) Digitizing and rectifying relevant nondigital geologic, hydrologic, and soils information available for the study area.

(3) Compiling a digital geotechnical database incorporating test pit, borehole, and laboratory data, and other information as available from geotechnical reports on file with communities in the study area, the Utah Department of Transportation, and Zion National Park.

(4) Incorporating current road and land parcel information into a GIS database.

(5) Creating GIS-based derivative geologic-hazard maps for the nine principal geologic hazards affecting the study area.

(6) Field checking and mapping as necessary to improve the geologic-hazard maps.

(7) Preparing this report containing study introductory information, and because data are insufficient to prepare an earthquake-site-conditions map, a section describing the ground-shaking hazard in the study area.

Each of the geologic-hazard maps prepared for this study (plates 1–9) is a stand-alone document that provides information on the data sources and techniques used to create the map, the nature and distribution of the hazard, and possible hazard-reduction measures. Available data are insufficient to prepare an earthquake-ground-shaking hazard map—details about the ground-shaking hazard in the study area are presented below. The study includes an ArcGIS 10.0 file geodatabase that contains all of the information used to develop the hazard maps. This geodatabase may be used directly in ArcGIS 10.0 or later versions, or in other GIS applications. Considering the map scale and limited geotechnical data, the special-study boundaries shown on the maps are considered approximate and are subject to change as additional information becomes available. Furthermore, small, unrecognized areas of hazard may exist in the study area, but their identification was precluded by limitations of data availability or map scale.

SOURCES OF INFORMATION

Although we compiled the data used in this study from a variety of sources (see individual geologic-hazard maps and earthquake-ground-shaking section below), the principal sources of information used for this study, in addition to the new databases specifically created for this project, include (1) the four UGS 7.5-minute geologic quadrangle maps (Virgin [Hayden and Sable, 2008], Springdale West [Willis and others, 2002], Springdale East [Doelling and others, 2002], and Smithsonian Butte [Moore and Sable, 2001] that lie entirely within or include portions of the SR-9 study area (figure 1); (2) Natural Resources Conservation Service (formerly Soil Conservation Service) *Soil Survey of Washington County Area, Utah* (Mortensen and others, 1977), which has been digitized by the Utah Automated Geographic Reference Center; (3) UGS Open-File Report 340, *Engineering Geologic Map Folio, Springdale, Washington County, Utah*, (Solomon, 1996); (4) UGS Special Study 127, *Geologic Hazards and Adverse Construction Conditions, St. George–Hurricane Metropolitan Area, Washington County, Utah* (Lund and others, 2008b); (5) UGS Special Study 133, *Geologic Hazards of the Zion National Park Geologic-Hazard Study Area, Washington and Kane Counties, Utah* (Lund and others, 2010); and (6) 40 site-specific geotechnical reports on file with communities in the study area, the Utah Department of Transportation, and Zion National Park.

SETTING

The SR-9 study area encompasses 97 square miles, and consists of a corridor ranging from about 2 to 8 miles wide and 15 miles long centered on SR-9, that extends from the western edge of the Virgin 7.5-minute quadrangle (Hayden and Sable, 2008) in La Verkin City to the Town of Springdale's eastern boundary with Zion National Park (figure 1). The northern and southern boundaries are irregular, but generally conform to the SR-9 corridor viewshed as defined in the *Zion Canyon Futures Study* (Utah State University, 2009). The study area includes all potentially developable land along SR-9 and contiguous areas that could source geologic hazards (chiefly localized flash floods and debris flows, rock falls, and landslides) that might affect existing or future development. The communities within the study area include the eastern part of La Verkin City, the northernmost part of the Town of Apple Valley, and the communities of Virgin, Rockville, and Springdale.

The study area is characterized by rugged topography that includes in its western part, dissected table lands at the top of the Hurricane Cliffs that have been incised by the Virgin River, and in its eastern part, lower Zion Canyon with its numerous side canyons and adjacent steep upland areas (figure 1). Vegetation is generally sparse except in riparian areas along perennial rivers and streams. The principal perennial drainages are the East and North Forks of the Virgin River, and below their confluence the Virgin River main stem, all of which generally flow from east to west across the study area (figures 1 and 2). North Creek (from the north) and Shunes Creek (from the southeast) are perennial tributaries to the Virgin River.

Several large ephemeral tributaries enter the Virgin River from the north (Dalton Wash, Coalpits Wash, Huber Wash, and Blacks Canyon) and south (Grafton Wash, Horse Valley Wash, and South Creek) (figure 1). Numerous small, unnamed ephemeral washes are also tributary to the Virgin River from both the north and south. Upland areas consist chiefly of large, flat-topped mesas (Hurricane Mesa, Smith Mesa, Rockville Bench, Gooseberry Mesa, Grafton Mesa, and Wire Mesa), numerous smaller buttes (e.g., Eagle Crags and Wire Valley Knoll), and intervening steep slopes and bedrock cliffs. Elevations in the study area range from approximately 6400 feet at South Mountain in the Vermilion Cliffs at the southeast corner of the study area to 3240 feet along the Virgin River at the western study area boundary (figure 1), an elevation difference of about 3160 feet.

State Route 9 and the Kolob Terrace Road (figure 1) are the principal (paved) transportation routes in the study area. Numerous unpaved roads ranging from well-graded gravel county roads to unmaintained two-wheel dirt tracks provide additional access within the study area.

All but the highest elevations in the study area are typified by a semiarid climate (10–20 inches of precipitation annually). Most precipitation comes in the form of intense, short-duration summer cloudburst storms and occasional longer duration, regional rainstorms generated by moisture from the Gulf of California in the summer and from the Pacific Ocean in the winter. A period of marked dryness occurs from mid-May to mid-July. There are two weather stations near the study area, one to the east in Zion National Park (429717) in lower Zion Canyon (elevation 4050 feet; period of record 1/1/1904 to present with some gaps), and the other in La Verkin City (424968) to the west (elevation 3200 feet; period of record 4/19/1950 to present) (Western Regional Climate Center, 2011a). Average annual precipitation at the Zion National Park weather station is 15.08 inches, and the average annual maximum and minimum temperatures are 75.1°F and 46.9°F, respectively. Average high temperatures in June, July, and August exceed 93°F, and average low temperatures in December and January are less than 30°F (Western Regional Climate Center, 2011a). At the La Verkin weather station, which is below the Hurricane Cliffs, average annual precipitation is 10.99 inches, and the average annual maximum and minimum temperatures are 75.9°F and 44.5°F, respectively. Average high temperatures in June, July, and August exceed 94°F, and average low temperatures in December and January are less than 30°F (Western Regional Climate Center, 2011b).

GEOLOGY

Numerous workers have studied the geology of southwestern Utah (see Rowley and others, 2006; Doelling, 2008; and Biek and others, 2010a, 2010b for extensive geologic reference lists). We limit our discussion here to a brief description of the geologic units, structures, and conditions pertinent to geologic hazards within the SR-9 study area. For readers interested in greater detail about the geology of the study area see Moore and Sable (2001), Doelling and others (2002), Willis and others (2002), and Hayden and Sable (2008).

The SR-9 study area lies within the Transition Zone between the comparatively simple geology of the high-standing Colorado Plateau to the east, and the geologically complex, lower-lying Basin and Range Province to the west (Stokes, 1977) (figure 2). The Transition Zone is several tens of miles wide in southwestern Utah and exhibits structural and stratigraphic characteristics of both physiographic provinces. The study area lies within a structural block that is bounded by the Sevier fault (Lund and others, 2008a) on the east and the Hurricane fault (Lund and others, 2007) on the west (figure 2); both are large-displacement, down-to-the-west, basin-and-range-style, normal-slip faults.

The trace of the Hurricane fault is marked by the high, steep Hurricane Cliffs, which are about a mile west of the SR-9 study area's western boundary (figure 3). The Hurricane fault has a higher Quaternary vertical slip rate than the Sevier fault, and uplift along the Hurricane fault has placed the study area at an intermediate structural position and elevation between the Colorado Plateau and Basin and Range physiographic provinces (figure 2). Because of its comparatively high structural and topographic position relative to the Basin and Range Province and the Colorado River, to which the perennial streams in the region are tributary, erosion is the chief geomorphic process in the study area. Rivers and streams are actively incising the western edge of the structural block and carving Zion Canyon and other canyons at an exceptionally high rate of about 1300 feet per million years (Biek and others, 2010b).

Figure 3. *Hurricane Cliffs mark the trace of the Hurricane fault in the City of La Verkin, about a mile west of the State Route 9 Corridor Geologic-Hazard Study Area western boundary (photo date 2008).*

Bedrock exposed in the study area ranges in age from the Permian Fossil Mountain Member of the Kaibab Formation (Hayden and Sable, 2008) to Quaternary basalt flows (Willis and others, 2002) (figures 4 and 5). The rock units represent a nearly 5000-foot section of chiefly marine and continental rock types that include limestone, mudstone, claystone, shale, sandstone, conglomerate, evaporite, and basalt. About 2000 feet of additional Mesozoic and Cenozoic sedimentary rocks have been eroded from the area and crop out only at higher elevations north and east of the study area. Some bedrock units contain a high percentage of clay and are correspondingly weak and moisture sensitive, making them susceptible to landslides and volumetric change (shrink/swell). Landslides associated with weak rock units are common in the study area, and frequently coalesce to form landslide complexes. More competent, cliff-forming rock formations are cut by large, through-going joint sets (figure 6), which make the formations susceptible to rock fall. Quaternary basalt flows are present in the study area. The flows originated from nearby volcanic cinder cones outside the study area boundaries. In nearby areas, some of the flows have been displaced vertically hundreds of feet by normal-slip faults.

Unconsolidated geologic units in the study area are of limited aerial extent and thickness due to the dominance of erosive geomorphic processes. Stream alluvium and terrace deposits of different ages are present along larger drainages, particularly the Virgin River in lower Zion Canyon. Alluvial fans have formed at the mouths of tributary drainages to lower Zion Canyon. The alluvial fans are typically small and often bury older terrace deposits. Because the debris-flood and debris-flow deposits forming the fans are generally poorly sorted and have low bulk densities, the fan deposits are often susceptible to soil collapse upon wetting.

Colluvium, rock-fall, and talus deposits (figure 6) mantle slopes formed on the Chinle, Moenave, and Kayenta Formations, where those rock formations crop out at the base of near-vertical Navajo Sandstone cliffs. The colluvium and talus deposits contain numerous rock-fall boulders that can be tens of feet in their longest dimension. Prehistoric large rock falls and in some instances basalt flows have blocked drainages in and tributary to Zion Canyon and created temporary natural dams behind which lake deposits accumulated. Future large rock falls could create new water impoundments either within

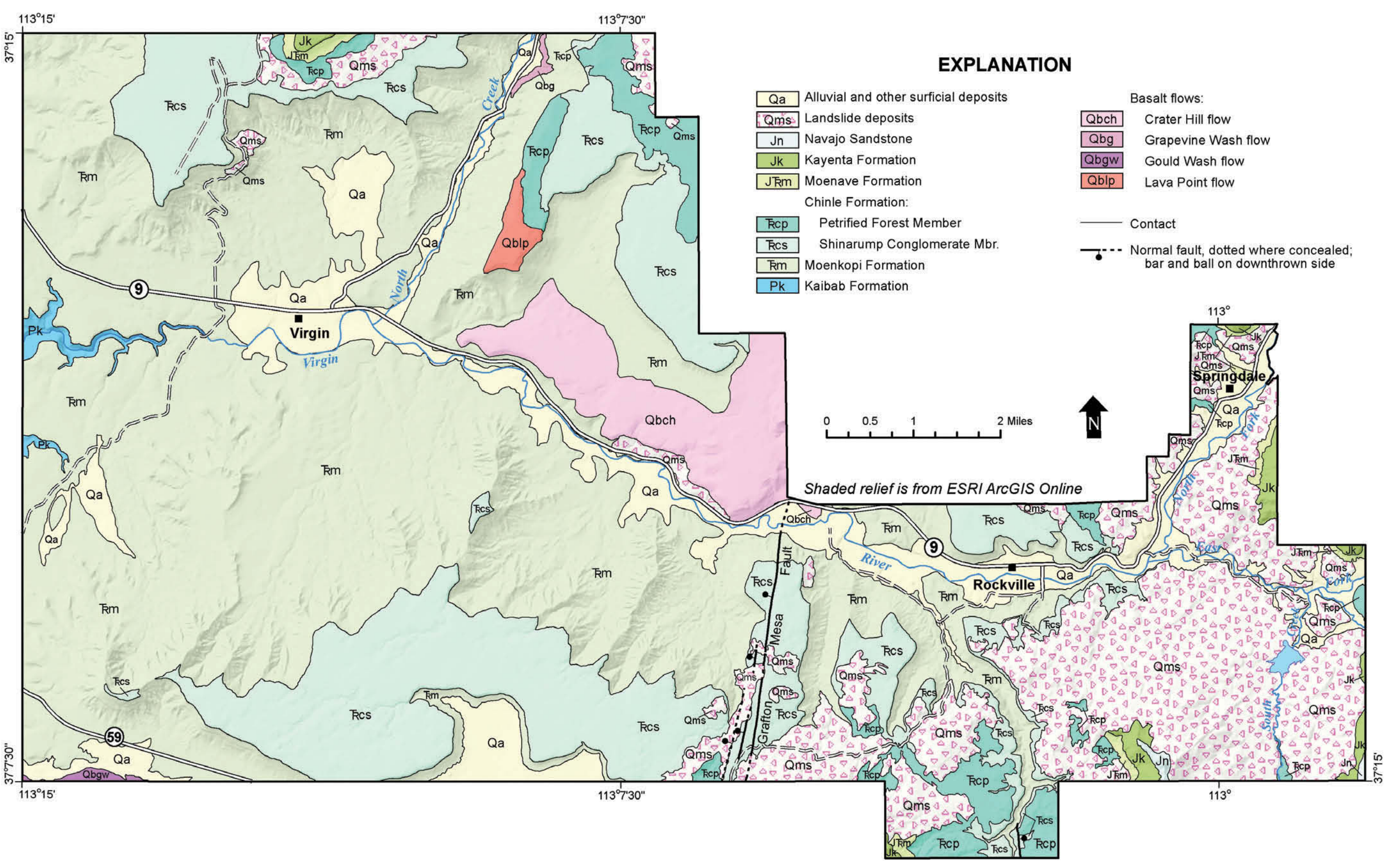

***Figure 4.** Simplified geologic map of the State Route 9 Corridor Geologic-Hazard Study Area (geology after Biek and others, 2010a).*

SYSTEM	SERIES	FORMATION	MEMBER	SYMBOL	THICKNESS feet (meters)	LITHOLOGY
QUAT.	HOLO. and PLEIST.	Surficial deposits		Q	0–50 (0–15)	
QUAT.	HOLO. and PLEIST.	Basalt flows and associated deposits		Qb	0–400 (0–120)	
JURASSIC	LOWER	Navajo Sandstone		Jn	800+ (245+)	Vertical cliffs
JURASSIC	LOWER	KAYENTA FM.	upper unit	Jk	550–700 (168–213)	Sandstone ledge
JURASSIC	LOWER	KAYENTA FM.	Springdale Sandstone Member	Jks	90–150 (27–46)	Vertical cliff
JURASSIC	LOWER	MOENAVE FM.	Whitmore Point Member	Jmw	60–80 (18–24)	Fish fossils *(Semionotus kanabensis)*
JURASSIC / TRIASSIC	LOWER	MOENAVE FM.	Dinosaur Canyon Member	JTRmd	175–210 (53–64)	J-0 unconformity
TRIASSIC	UPPER	CHINLE FM.	Petrified Forest Member	TRcp	350–450 (105–135)	Variegated or banded slope "Popcorn" weathering Covered by landslides
TRIASSIC	UPPER	CHINLE FM.	Shinarump Conglomerate Member	TRcs	80–200 (24–60)	Fossil wood; TR-3 unconformity
TRIASSIC	LOWER	MOENKOPI FORMATION	upper red member	TRmu	300–450 (90–135)	
TRIASSIC	LOWER	MOENKOPI FORMATION	Shnabkaib Member	TRms	350–500 (105–150)	Gypsum
TRIASSIC	LOWER	MOENKOPI FORMATION	middle red member	TRmm	200 (60)	
TRIASSIC	LOWER	MOENKOPI FORMATION	Virgin Limestone Member	TRmv	100–130 (30–40)	
TRIASSIC	LOWER	MOENKOPI FORMATION	lower red member	TRml	160–250 (40–75)	
TRIASSIC	LOWER	MOENKOPI FORMATION	Timpoweap Member	TRmt	130 (40)	Oil seeps Cherty conglomerate
TRIASSIC	LOWER	MOENKOPI FORMATION	Rock Canyon Conglomerate Member	TRmr	0–7 (0–2)	TR-1 unconformity
PERMIAN	LOWER	KAIBAB FM.	Harrisburg Member	Pkh	160 (50)	
PERMIAN	LOWER	KAIBAB FM.	Fossil Mountain Member	Pkf	200+ (60+)	Brachiopods "Black-banded"

Figure 5. *Lithologic column of geologic units that crop out in the SR-9 study area (modified from Biek and others, 2010b).*

Figure 6. *Jointed cliffs of Navajo Sandstone (upper cliffs) have produced numerous rock falls within Zion Canyon. Colluvium, talus, and rock-fall deposits mantle underlying bedrock formations (photo date 2011).*

or upstream from the study area, with the accompanying possibility of severe flooding either behind the rock-fall barrier as the water impoundment fills or downstream if a rock-fall dam breaches catastrophically. In upland areas, generally thin units of mixed eolian, alluvial, and colluvial material mantle shallow bedrock.

Geologic structure in the study area is typified by gently east-dipping (3–5°) sedimentary strata. However, several basin-and-range-style normal-slip faults displace rock units in and near the study area (figure 7). The largest of these is the down-to-the-west Hurricane fault, about a mile west of the western study area boundary (figures 1, 3, and 7). At nearly 160 miles long, the Hurricane fault is the longest normal-slip fault in southwestern Utah. Net vertical displacement of the fault exceeds 2000 feet (Anderson and Christenson, 1989; Lund and others, 2007). Abundant geologic evidence shows that the Hurricane fault has generated numerous large-magnitude surface-faulting earthquakes in the late Quaternary (Lund and others, 2007). Other normal-slip faults in or near the study area have displacements that are measured in hundreds rather than thousands of feet (Biek and others, 2010b; Lund and others, 2010). Relations with bedrock and unconsolidated deposits, chiefly volcanic basalt flows, indicate that these faults have lower vertical slip rates than the Hurricane fault, although their style and sense of movement are consistent with the region's current extensional tectonic regime.

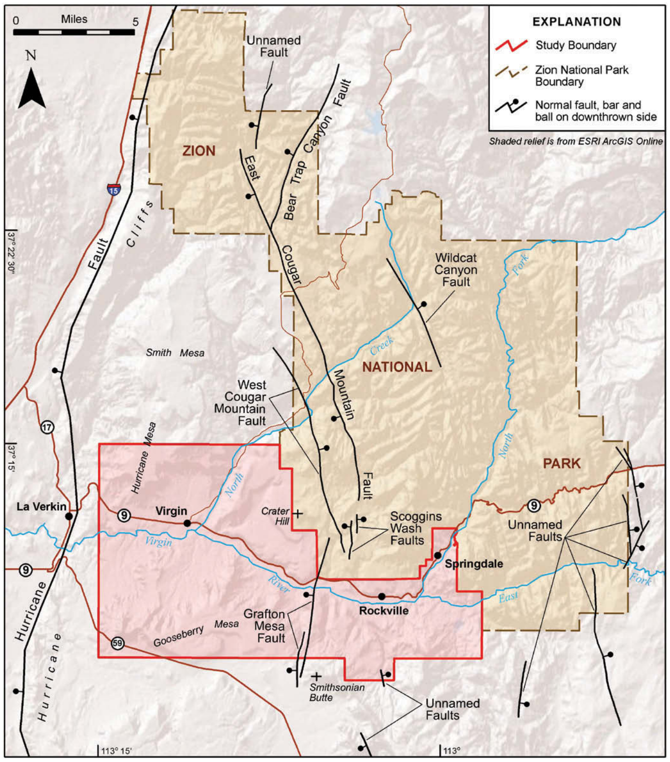

Figure 7. Normal-slip faults in and near the State Route 9 Corridor Geologic-Hazard Study Area.

EARTHQUAKE-GROUND-SHAKING HAZARD

Introduction

Ground shaking is the most widespread and typically the most costly earthquake hazard in terms of property damage, injury, and death (Yeats and others, 1997). Ground shaking is caused by seismic waves that originate at the source of the earthquake and radiate outward in all directions. The strength of ground shaking generally decreases with increasing distance from the earthquake epicenter because the earthquake's energy scatters and dissipates as it travels through the Earth. However, in certain cases earthquake ground motions can be amplified and shaking duration prolonged by local site conditions (Hays and King, 1982; Wong and others, 2002). The degree of amplification depends on factors such as soil thickness and the characteristics of geologic materials.

The extent of property damage and loss of life due to ground shaking depends on specific factors such as (1) the strength and duration of the earthquake, (2) the proximity of the earthquake to an affected location, (3) the amplitude, duration, and frequency of earthquake ground motions, (4) the nature of the geologic materials through which the seismic waves travel, and (5) the design of engineered structures (Costa and Baker, 1981; Reiter, 1990). A building need only withstand the vertical force of gravity to support its own weight. However, during an earthquake a building is also subjected to horizontal forces. Horizontal ground motions are typically the most damaging type of earthquake ground shaking, and are expressed in decimal fractions of the acceleration due to gravity (1 *g*). Horizontal ground motions as small as 0.1 g may cause damage to weak structures (buildings not designed to modern building codes incorporating seismic design) (Richter, 1958), and in a large earthquake, horizontal motions may reach values greater than that of gravity. Consequently, the type and quality of construction play critical roles in determining the damage caused by strong ground shaking.

Sources of Information

Sources of information used to evaluate the earthquake-ground-shaking hazard in the SR-9 study area include (1) the four UGS 7.5-minute geologic quadrangle maps (Virgin [Hayden and Sable, 2008], Springdale West [Willis and others, 2002], Springdale East [Doelling and others, 2002], and Smithsonian Butte [Moore and Sable, 2001]) that lie entirely within or include portions of the SR-9 study area (figure 1); (2) information on historical earthquakes in southwestern Utah and northwestern Arizona, chiefly from the University of Utah Seismograph Stations earthquake catalog (University of Utah Seismograph Stations, 2011a), (3) the *Quaternary Fault and Fold Database of the United States* (U.S. Geological Survey [USGS], 2011a), (4) the *Quaternary Fault and Fold Database of Utah* (Black and others, 2003), and (5) 40 site-specific geotechnical reports on file with communities in the study area, the Utah Department of Transportation, and Zion National Park.

Anderson and Christenson (1989) reviewed Quaternary faulting and folding in southwestern Utah including the SR-9 study area, and the characteristics and consequences of the M_L 5.8 1992 St. George earthquake are documented in a volume edited by Christenson (1995). Studies by Pearthree and others (1998), Stenner and others (1999), Lund and others (2001, 2002, 2007, 2008a), and Amoroso and others (2004) present paleoseismic information for the Hurricane and Sevier faults. UGS Special Study 133, *Geologic Hazards of the Zion National Park Geologic-Hazard Study Area, Washington and Kane Counties, Utah* (Lund and others, 2010), provides information on the short, normal-slip faults in and adjacent to the SR-9 study area.

The principal sources of information for evaluating earthquake ground shaking in the SR-9 study area were the USGS National Seismic Hazard Maps (NSHM) (USGS, 2011b), *2009 International Building Code* (IBC) (International Code Council, 2009a), and *2009 International Residential Code for One- and Two-Family Dwellings* (IRC) (International Code Council, 2009b).

Earthquakes in Southwestern Utah

Large, damaging earthquakes are a rare occurrence in southwestern Utah, but faults in and near the SR-9 study area (figures 2 and 7) are capable of producing earthquakes as large as magnitude 6.5–7.0 (Lund and others, 2007, 2008a). Earthquakes in southwestern Utah are typically associated with the Intermountain Seismic Belt (ISB) (Smith and Sbar, 1974; Smith and Arabasz, 1991), an approximately 100-mile-wide, north-south-trending zone of earthquake activity that extends from northern Montana to northwestern Arizona (figure 8). In an average year, Utah experiences more than 700 earthquakes, but most are too small to be felt (University of Utah Seismograph Stations, 2011b). Moderate (M 5.5–6.5) earthquakes happen every several years on average, the most recent being the M_L 5.8 St. George earthquake on September 2, 1992. Large earthquakes (M > 6.5) occur much less frequently; however, geologic evidence shows that southwestern Utah has experienced numerous large surface-faulting earthquakes in the Holocene (past approximately 11,700 years) (Black and others, 2003; Lund and others, 2007, 2008a).

Earthquakes in the ISB are chiefly associated with normal-slip faults. Normal faults form in response to tensional (pulling apart) forces, typically dip between 45 and 90 degrees, and place younger rock on older rock (see plate 8, surface-fault-rupture hazard map). Tensional forces have characterized the regional stress regime in southwestern Utah for the past several million years. Consequently, normal faults in and near the SR-9 study area (figures 2 and 7) are typically geologically young and many, if not most, are considered capable of producing earthquakes. In the Basin and Range Province and adjacent areas of Utah, the larger and more active faults, such as the Wasatch fault, may generate large earthquakes every few hundred years. However, most normal-slip faults in the Basin and Range Province are less active and produce large earthquakes and surface faulting having repeat times of thousands to tens of thousands of years.

Potential Sources of Strong Earthquake Ground Shaking

Potential sources of strong earthquake ground shaking in the SR-9 study area include (1) the Hurricane fault (figures 2, 3, and 7), (2) the comparatively short normal-slip faults with very long recurrence intervals within or close to the study area (figure 7), (3) the Sevier fault about 15 miles east of the study area (figure 2) (Lund and others, 2008a), and (4) a random background earthquake with a magnitude below the threshold required to produce surface rupture (~ M 6.5) that occurs either within or near the study area on an unrecognized fault. While all of these sources could potentially produce strong ground shaking, the shorter normal faults and the Sevier fault have very long recurrence intervals for moderate to large earthquakes, and are unlikely to produce strong ground shaking in the study area. However, the Hurricane fault shows evidence for large, surface-faulting earthquakes during the Holocene (Lund and others, 2007), and an earthquake ≥ M 6.5 on the Hurricane fault near the study area within the next several decades cannot be discounted. Similarly, a moderate-magnitude (M 5.0–6.5) background earthquake in or near the study area is also a possibility.

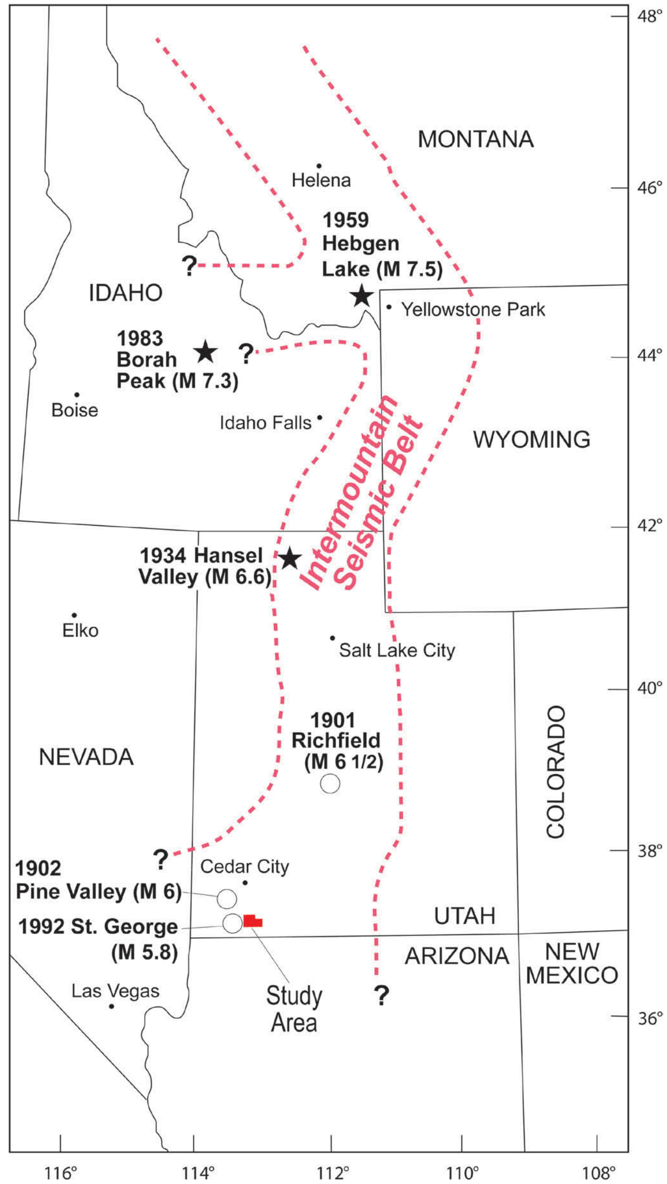

Figure 8. *The Intermountain Seismic Belt and major historical ISB earthquakes. Stars indicate surface-faulting earthquakes.*

Ground Shaking Hazard Reduction

Insufficient geotechnical data exist to prepare an earthquake-site-conditions map for the SR-9 study area. However, risk to public safety due to earthquake ground shaking can be reduced by incorporating building-code-based earthquake-resistant construction requirements in new construction and when retrofitting existing structures. In Utah, earthquake-resistant design requirements are specified in the seismic provisions of the *2009 International Building Code* (IBC) (International Code Council, 2009a) and the *2009 International Residential Code for One- and Two-Story Dwellings* (IRC) (International Code Council, 2009b), which are adopted statewide. We recommend that communities within the SR-9 study area closely adhere to these code requirements (or subsequent code updates). Additionally, we recommend review and consideration of the Federal Emergency Management Agency (2005) document *Earthquake Safety Guide for Homeowners* (http://www.pdc.org/pdf/preparedness/fema530.pdf), which contains recommendations for earthquake-proofing homes, and *Putting Down Roots in Earthquake Country—Your Handbook for Earthquakes in Utah* (http://www.ussc.utah.gov/publications/roots_earthquake.pdf) (Utah Seismic Safety Commission, 2008), which contains information on Utah's earthquake hazard and earthquake mitigation and preparedness.

Special investigations are required to ensure that buildings and other structures will be designed and constructed to resist the effects of earthquake ground motions. These effects may be particularly severe in areas subject to amplified ground motions. IBC site classes (table 3) for all projects should always be confirmed in the field as outlined in the IBC or IRC. In general, site class is determined by conducting a geotechnical investigation during the project design phase prior to construction.

For construction in areas underlain by rock subject to deamplification (Site Class A) or no amplification (Site Class B), site geological and geotechnical investigations are needed to confirm the mapped site class based on rock type. However, as amplification increases in Site Classes C, D, and E, more detailed subsurface investigations should be conducted for all types of development intended for human occupancy, and for critical facilities regardless of occupancy category. For construction in areas underlain by soil of Site Classes C, D, or E, a geotechnical investigation is needed to characterize site soil conditions. Investigations in Salt Lake Valley have shown that site classes may vary at a site between adjacent boreholes (Ashland and McDonald, 2003), making an appropriate level of conservatism necessary when performing geotechnical investigations, particularly at sites with variable geology. The IBC requires that both site-specific geotechnical investigations and dynamic site-response analyses be performed in areas underlain by Site Class F materials. Site Class F includes collapse-prone soils that are common locally in the SR-9 study area. In some cases, as a default option, the IBC allows use of Site Class D except where the local building official determines that Site Class E or F is likely to be present.

We recommend that IBC or IRC site classes be determined on a site-specific basis for new construction in the SR-9 study area. The USGS U.S. Seismic Design Maps Web Application (USGS, 2012) (http://geohazards.usgs.gov/designmaps/us/) provides seismic design parameters applicable to IBC or IRC design and construction requirements for resisting earthquake motions. Additionally, historic structures constructed of unreinforced brick or stone masonry, adobe structures, and other structures built prior to the general adoption of seismic design criteria (typically pre-1975) are particularly vulnerable to ground shaking. We recommend that structures in those

Table 3. *2009 International Building Code site-class definitions (from 2009 IBC table 1613.5.2).*

Site Class	Soil Profile Name	Average Properties in Top 100 Feet		
		Shear-Wave Velocity - v_s (ft/s)	**Standard Penetration Resistance - *N* (blows/ft)**	**Undrained Shear Strength - s_u (psf)**
A	Hard rock	>5000	n.a.	n.a.
B	Rock	2500–5000	n.a.	n.a.
C	Very dense soil and soft rock	1200–2500	>50	>2000
D	Stiff soil	600–1200	15–50	1000–2000
E	Soft soil	<600	<15	<1000
E	---	Any profile with more than 10 feet of soil having the following characteristics: 1. Plasticity index >20 2. Moisture content ≥40% 3. Undrained shear strength <500 psf		
F	---	Any profile containing soils having one or more of the following characteristics: 1. Soils vulnerable to potential failure or collapse under seismic loading such as liquefiable soils, quick and highly sensitive clays, collapsible weakly cemented soils 2. Peats and/or highly organic clays (>10 feet thick) 3. Very high plasticity clays (>25 feet thick with plasticity index >75) 4. Very thick (>120 feet) soft/medium stiff clays		

categories be evaluated to determine their ability to withstand strong earthquake ground shaking, and where appropriate, be seismically retrofitted to improve their life safety capability (see Utah Seismic Safety Commission online publication *The Utah Guide to Seismic Improvement of Unreinforced Masonry Dwellings* at http://ussc.utah.gov/utahseismic/index.html), and *Putting Down Roots in Earthquake Country—Your Handbook for Earthquakes in Utah* (http://www.ussc.utah.gov/publications/roots_earthquake.pdf) (Utah Seismic Safety Commission, 2008) for background information.

SUMMARY

The communities of La Verkin, Virgin, Rockville, and Springdale are subject to a variety of geologic hazards (table 1). Because of their wide distribution, frequent occurrence, and destructive potential, we expect floods, rock falls, landslides, collapsible soil, and expansive soil and rock to be the principal geologic hazards that will affect the SR-9 study area in the future. With the exception of the effects (surface-fault rupture, strong earthquake ground shaking, and liquefaction) of an infrequent, but potentially catastrophic large earthquake, the remaining geologic hazards considered in this study (gypsiferous soil and rock, soil piping and erosion, and wind-blown sand) are typically localized, and while potentially costly when not recognized and properly accommodated in project planning, design, and maintenance, the problems associated with them are rarely life threatening.

The geologic-hazard maps (plates 1–9) accompanying this report are intended for use in general planning to indicate where site-specific geologic-hazard investigations are necessary. This report provides a discussion of the earthquake-ground-shaking hazard in the study area, but available data are insufficient to prepare an earthquake-site-conditions map. We recommend a site-specific geotechnical investigation for all new construction in the study area, and a geologic assessment to identify potential geologic hazards at sites within special-study areas shown on the maps accompanying this report. Site-specific investigations can resolve uncertainties inherent in these 1:24,000-scale maps, and help increase safety by identifying the need for special construction design or hazard mitigation.

In addition to the references at the end of this document and on the accompanying geologic-hazard maps, the UGS "Earthquakes and Geologic Hazards" web page at http://geology.utah.gov/utahgeo/hazards/index.htm provides additional general information on geologic hazards in Utah. Additionally, the UGS web page for consultants and design professionals (http://geology.utah.gov/ghp/consultants/index.htm) includes information on recommended report guidelines, UGS geologic-hazard maps and reports, geologic maps, groundwater reports, historical aerial photography, and other sources of useful information. We recommend following UGS guidelines when preparing site-specific engineering-geologic reports and conducting site-specific hazard investigations in the SR-9 study area. Typically, engineering-geologic 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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