UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources

EXPLANATION

H **High** - Areas where steep slopes below resistant cliff-forming bedrock units provide acceleration and runout zones littered with abundant rock-fall boulders ≥1.5 feet in diameter. Such large boulders can damage property and threaten lives. Rock units in high-hazard areas include the Shinarump Conglomerate Member of the Chinle Formation, Springdale Sandstone Member of the Kayenta Formation, Navajo Sandstone, and Quaternary basalt flows. Where jointed or fractured, these rock units can produce large (>30 feet in long dimension) angular boulders.

M **Moderate** - Areas where (1) slopes provide sufficient relief to create an acceleration zone, but where only sparse rock-fall debris is present on slopes or in the runout zone at the base of the slope; typically bedrock units in these areas crop out in the slope instead of forming a capping unit, or where a capping unit is present, the resulting rock-fall debris is typically <1.5 feet in diameter; or (2) talus/cliff-retreat deposits form steep slopes due to erosion and previous rock-fall boulders on those slopes may remobilize.

L **Low** - Areas where fine-grained, comparatively soft bedrock units such as mudstone and shale crop out on steep slopes, or where rock units typical of moderate- or high-hazard categories crop out in areas of low to moderate relief. Low-hazard areas typically contain sparse rock sources of limited extent.

INTRODUCTION

Homes, other buildings, and vehicles have been struck and severely damaged from rock falls in the State Route 9 Corridor Geologic-Hazard Study Area (SR-9 study area) (figure 1; Lund, 2002; Knudsen, 2011; 2012). Rock fall is a natural mass-wasting process that involves the dislodging and downslope movement of individual rocks and rock masses (Cruden and Varnes, 1996). Rock falls pose a threat because falling or rolling boulders can damage property and cause injury or even loss of life. The probability of a damaging/life threatening rock fall is greatly increased where permanent facilities are located in rock-fall-hazard zones (figure 2). Rock-fall hazards exist where a source of rock is present above slopes steep enough to allow rapid downslope movement of dislodged rocks by falling, rolling, and bouncing.

Rock-fall hazard 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 cliffs, bluffs, and terraces. Talus cones and scree-covered slopes are indicators of a high rock-fall hazard, but other less obvious areas may also be vulnerable.

Rock falls are initiated by freeze/thaw action, rainfall, weathering and erosion of the rock and/or surrounding material, and root growth. Rock fall is also the most common type of mass movement caused by earthquakes. Keefer (1984) indicated that earthquakes as small as magnitude (M) 4.0 can trigger rock falls. All nine of Utah's historical earthquakes of M 5 or greater have caused rock falls. Sources of earthquake ground shaking that might produce rock falls in the SR-9 study area include a large earthquake (~M 6.5) on the Hurricane fault west of the study area, or a moderate earthquake (~M 6.5) within the study area itself (Ivan Wong, URS Corporation, written communication, 2008).

Slope modification, such as cuts for roads and building pads or clearing of slope vegetation for development, can increase or create a local rock-fall hazard. However, in many cases, a specific triggering event is not apparent. Although not well documented, rock falls in Utah appear to occur more frequently during spring and summer months. This is likely due to spring snowmelt, summer cloudburst storms, and large daily temperature variations (Castleton, 2009).

Figure 1. Rockville home at 200 North Center Street damaged by a rock-fall boulder on October 18, 2001.

Figure 2. Permanent development in rock-fall hazard zones below Rockville Bench in Rockville. Rockville Bench is typical of many exposures in the study area where softer bedrock units crop out on slopes below more resistant cliff-forming formations. Photo date: February 2011.

SOURCES OF INFORMATION

Sources of information used to evaluate rock-fall hazard in the SR-9 study area include (1) the four Utah Geological Survey (UGS) 1:24,000-scale geologic quadrangle maps that cover the study area (Virgin [Hayden and Sable, 2008], Springdale West [Willis and others, 2002], Springdale East [Doelling and others, 2002], and Smithsonian Butte [Moore and Sable, 2001]), (2) *Engineering Geology of the St. George Area, Washington County, Utah* (Christenson and Deen, 1983), (3) *Landslide Maps of Utah* (Elliott and Harty, 2010), (4) "Geologic Hazards of the St. George Area, Washington County, Utah" (Christenson, 1992), (5) "Landslide Distribution and Hazards in Southwestern Utah" (Harty, 1992), (6) *Engineering Geologic Map Folio, Springdale, Washington County, Utah* (Solomon, 1996), (7) *Landslide Susceptibility Map of Utah* (Giraud and Shaw, 2007), (8) *Geologic Hazards and Adverse Construction Conditions, St. George–Hurricane Metropolitan Area, Washington County, Utah* (Lund and others, 2008), and (9) *Geologic Hazards of the Zion National Park Geologic-Hazard Study Area, Washington and Kane Counties, Utah* (Lund and others, 2010).

ROCK-FALL SOURCES

Rock fall is the most common mass-movement type in the SR-9 study area. The combination of steep slopes capped by well-jointed, resistant bedrock formations provides ample opportunity to generate rock falls. Bedrock units particularly susceptible to rock fall in the study area include the Shinarump Conglomerate Member of the Chinle Formation; Springdale Sandstone Member of the Kayenta Formation; other ledge- and cliff-forming strata in the Moenkopi, Moenave, and Kayenta Formations; and the massive, pervasively jointed, cliff-forming Navajo Sandstone (figure 3). Rock falls are particularly prevalent and hazardous where softer, more easily eroded bedrock units crop out on slopes below stronger, more resistant bedrock formations (figure 2). Erosion of the underlying soft units and consequent undercutting of the more resistant bedrock formations triggers many rock falls.

Talus deposits blanket steep to moderate slopes throughout the study area. These deposits are derived from upslope ledges and cliffs and consist chiefly of accumulations of poorly sorted, coarse, angular blocks of various sizes. The widespread distribution of talus and the direct relation of talus deposits to the rock-fall process attest to the widespread extent of the rock-fall hazard in the study area.

Most rock falls in the SR-9 study area are localized events that affect a comparatively small area close to the base of cliffs and steep slopes (figure 4). High Navajo Sandstone cliffs in lower Zion Canyon may also be subject to infrequent, low-probability, high-hazard rock falls. However, evidence for very large rock falls in lower Zion Canyon is generally lacking. The absence of evidence may be related to the fact that in the lower canyon, large bedrock fins and other sources of large rock falls present in the upper, narrower part of the Zion Canyon have been removed as the canyon widened, and because the Virgin River is now a greater distance from the base of the canyon walls and therefore is no longer creating unstable undercutting conditions. Therefore, while very large rock falls (likely joint controlled rather than produced by undercutting) are still possible in lower Zion Canyon, they are infrequent events with return periods of hundreds and possibly thousands of years.

Figure 3. Rock-fall boulders near Springdale below well-jointed cliffs of Navajo Sandstone and the Springdale Sandstone Member. Photo date: January 2012.

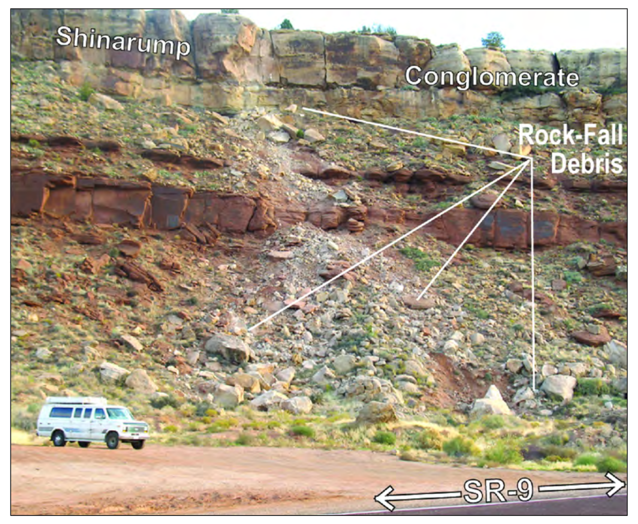

Figure 4. Rock-fall debris from a November 2010 rock fall in Rockville covers a relatively small area near the base of Rockville Bench.

ROCK-FALL-HAZARD CLASSIFICATION

This map shows areas in the SR-9 study area that are susceptible to rock fall. Determining the severity of rock-fall hazard requires evaluating the characteristics of three hazard components: (1) a rock source, in general defined by bedrock geologic units that exhibit relatively consistent patterns of rock-fall susceptibility throughout the study area, although talus/cliff-retreat deposits may also create a local source of rock falls, (2) an acceleration zone, where the rock-fall debris gains momentum as it travels 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 finally (3) a runout zone, which includes gentler slopes where boulders roll or bounce before coming to rest beyond the base of the acceleration zone (Evans and Hungr, 1993; Wieczorek and others, 1998) (figure 5).

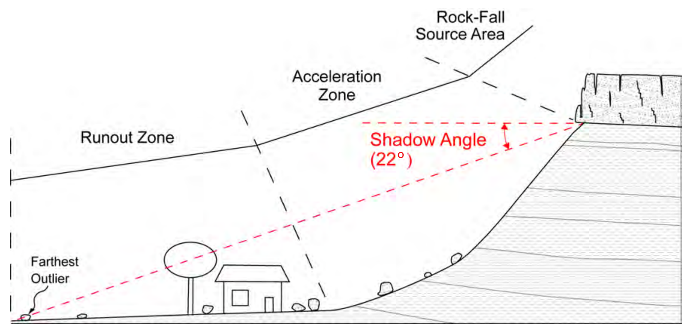

Figure 5. Components of a characteristic rock-fall path profile (modified from Lund and others, 2008).

We established the boundaries of areas subject to rock-fall hazard in the study area by measuring a shadow angle (Evans and Hungr, 1993; Wieczorek and others, 1998), which is the angle formed between a horizontal line and a line extending from the base of the rock source to the outer limit of the runout zone (figure 5). Shadow angles vary based on rock type, boulder shape, slope steepness, slope roughness, and rock source height. We measured shadow angles for dozens of representative rock-fall boulders in the SR-9 study area. Our investigation showed that a shadow angle of 22° is generally applicable in the study area, and defines a hazard zone sufficiently wide to include the limits of rock-fall debris that accumulates at the base of cliffs and steep slopes.

Our investigation also showed that while most rock-fall deposits in the study area accumulate in comparatively narrow, well-defined zones at the base of steep slopes, there are a few areas where large boulders are present beyond the limits of normal rock-fall accumulation. Many gently to moderately sloping benches lining the North and East Forks of the Virgin River near the Town of Springdale are mantled with mixed mass-movement, colluvial, and alluvial pediment-mantle deposits that contain large (some house-sized) boulders of chiefly Navajo Sandstone that are up to 1.5 miles from the nearest Navajo outcrop (figure 6). These boulders are likely talus/cliff-retreat deposits (some could be fin-collapse or large rock-avalanche deposits) left isolated by canyon widening, and are not representative of the current rock-fall hazard sourced from distant Navajo canyon walls. However, many of these boulders lie on locally moderate to steep slopes and could present a local hazard if remobilized.

Figure 6. Isolated, large boulders of Navajo Sandstone considered to be cliff-retreat deposits litter slopes above homes in Springdale. Photo date: February 2011.

We also observed numerous large boulders of Shinarump Conglomerate littering abandoned alluvial terraces and other surfaces below Rockville Bench and Wire, Grafton, Gooseberry, and Hurricane Mesas that are up to 1 mile away from the nearest Shinarump outcrop (figure 7). Knudsen (2011, 2012) documented large (up to 30 feet in long dimension), isolated boulders of Shinarump Conglomerate near the center of Rockville with shadow angles of less than 15°. He concluded that the boulders are likely cliff-retreat deposits and that they do not represent the extent of current rock-fall hazard. Biek and others (2012) reported additional isolated Shinarump boulders on an abandoned terrace 0.5 mile west of Rockville, and they concluded that the boulders fell onto the terrace at a time when the distant Shinarump-capped mesa to the northeast (Rockville Bench) was much closer to the terrace than it is today. While such cliff-retreat boulders are not representative of the current rock-fall hazard sourced from adjacent Shinarump-capped mesas, some near the eroded edges of elevated abandoned terraces could present a local hazard if remobilized.

The rock-fall-hazard categories are described in the Explanation section.

Figure 7. Isolated boulder of Shinarump Conglomerate that is too far from its source area (Shinarump-capped Hurricane Mesa in distance) to have been deposited in recent times.

USING THIS MAP

This map shows areas of relative rock-fall hazard in the SR-9 study area. Site-specific rock-fall-hazard investigations should be performed for future development in the study area as recommended in table 1. An experienced geotechnical engineer should provide design or site-preparation recommendations as necessary to reduce the rock-fall hazard. 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 some 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. Rock-fall sources should be evaluated for the following parameters: rock type, joints and other fractures, bedding planes, and potential clast size. Slopes below rock sources should be evaluated for slope angle, aspect, substrate, surface roughness, and vegetation. Previous rock-fall deposits should be evaluated for distribution, clast-size range, amount of embedding, and weathering of rock-fall boulders. In addition, evaluation of the runout zone below a source can be estimated using a simple two-dimensional model, such as the Colorado Rock Fall Simulation Program (Jones and others, 2000).

Table 1. Recommended requirements for site-specific investigations related to rock-fall hazards to protect life and safety.

Hazard Potential	Occupancy Category[1]				
	I	II		III	IV
	Buildings and Other Structures That Represent a Low Hazard to Human Life in the Event of Failure	One- and Two-Family Dwellings and Townhouses	All Other Buildings and Structures Except Those Listed in Categories I, 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
High, Moderate	No[2]	Yes	Yes	Yes	Yes
Low	No[2]	Yes	Yes	Yes	Yes
None	No	No	No	No	No

[1]Modified from International Code Council (2009).
[2]Property damage possible, but little threat to life safety.

HAZARD REDUCTION

Early recognition and avoiding areas subject to rock fall are the most effective means of reducing rock-fall hazard. However, avoidance may not always be a viable or cost-effective option, especially for existing development, and other techniques are available to reduce potential rock-fall damage. These may include, but are not limited to, rock stabilization, engineered structures, and modification of at-risk structures or facilities. Rock-stabilization methods are physical means of reducing the hazard at its source using rock bolts and anchors, steel mesh, or shotcrete on susceptible outcrops. Engineered catchment or deflection structures such as berms or benches can be placed below source areas, or at-risk structures themselves could be designed to stop, deflect, retard, or retain falling rocks. In areas where a site-specific evaluation indicates that rock falls are possible, but the rock-fall hazard is low, disclosure of the hazard to landowners and residents may be an acceptable alternative to avoidance or costly hazard-reduction efforts. Disclosure ensures that buyers are informed of the hazard and are willing to accept the associated risks.

MAP LIMITATIONS

The map boundaries between rock-fall-hazard categories are approximate and subject to change as new information becomes available. The rock-fall hazard at any particular site may be different than shown because of geological variations within a map unit, gradational and approximate map-unit boundaries, and map scale. Small, localized areas of higher or lower rock-fall hazard may exist within any given map area, but their identification is precluded because of limitations of the map scale. This map does not consider rock-fall hazards caused by cuts, fills, or other alterations to the natural terrain. This map is not intended for use at scales other than the published scale, and is designed for use in general planning and design to indicate the need for site-specific investigations.

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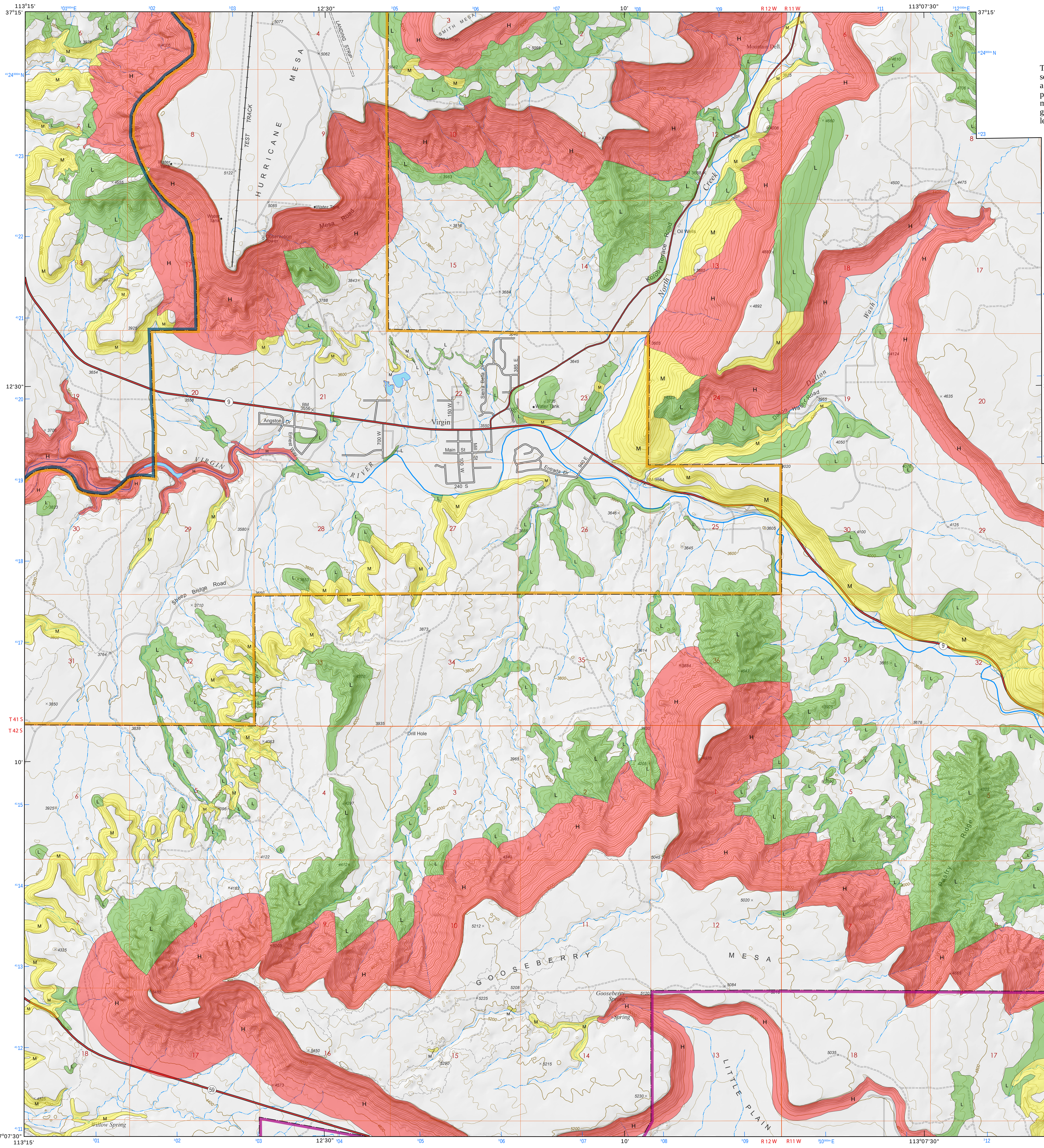
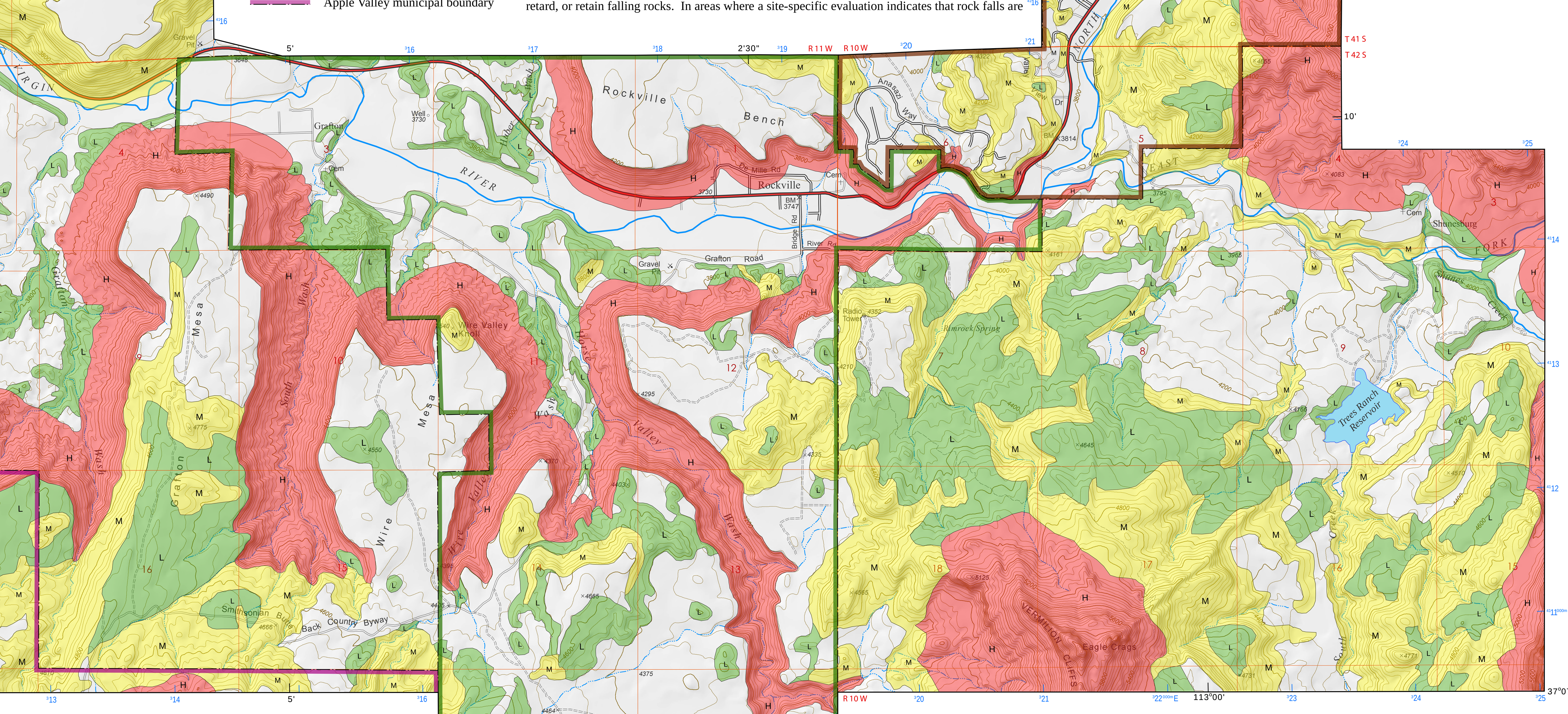
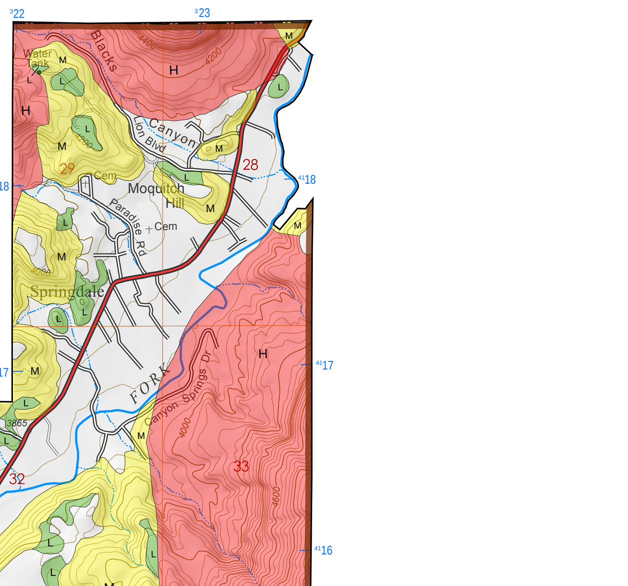
MAP SYMBOLS

- State highway
- Primary paved road
- Secondary paved road
- Improved road
- Unimproved road
- Trail
- Springdale municipal boundary
- Rockville municipal boundary
- Virgin municipal boundary
- La Verkin municipal boundary
- Apple Valley municipal boundary







11°42'
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 2013

SCALE 1:24,000
1 0.5 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 0.5 0 1 KILOMETER
CONTOUR INTERVAL 40 FEET

UTAH
MAP LOCATION

ROCK-FALL HAZARD
STATE ROUTE 9 CORRIDOR GEOLOGIC-HAZARD STUDY AREA, WASHINGTON COUNTY, UTAH

by
Tyler R. Knudsen and William R. Lund

2013

1. Pintura
2. Smith Mesa
3. The Guardian Angels
4. Temple of Sinawava
5. Hurricane
6. **Virgin**
7. **Springdale West**
8. **Springdale East**
9. The Divide
10. Little Creek Mountain
11. **Smithsonian Butte**
12. Hildale

7.5' QUADRANGLE INDEX

Base-map topographic contours and shaded relief derived from 10 meter U.S. Geological Survey National Elevation Dataset.

Geographic labels from U.S. Geological Survey 7.5-minute quadrangle maps acquired from the Utah Automated Geographic Reference Center.

Projection: UTM Zone 12
Datum: NAD 1983
Ellipsoid: GRS 80

GIS and Cartography: Tyler R. Knudsen

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