DISCUSSION

Landslides are downslope movements of rock or soil under the influence of gravity that are characterized by rotational or translational movement along a buried slip surface. Some landslides are deep-seated and move slowly over long periods of time, whereas others are shallow and move rapidly in a single event. **This map shows areas of relative landslide hazard for natural slopes under static (non-earthquake) conditions. Slopes considered unstable under static conditions will be even less stable during an earthquake**, and some slopes that are stable under static conditions may also fail as a result of earthquake ground shaking, particularly if wet. **Development can increase the potential for landsliding** if careful consideration is not given to structure design and siting, grading and other slope modifications, and increased ground moisture from on-site wastewater disposal, landscape irrigation, or changes in site drainage.

Landsliding has been one of the most damaging geologic hazards in the Springdale area. A landslide on September 2, 1992, associated with the Richter magnitude (M_L) 5.8 St. George earthquake, destroyed three homes in Springdale and forced the evacuation of condominiums and businesses in the path of the slide (Black and others, 1995; Jibson and Harp, 1995). A landslide on April 12, 1995, associated with a prolonged period of above-average precipitation, dammed the Virgin River in Zion National Park (three miles [5 km] north of Springdale) and disrupted drinking-water supplies in the park and Springdale, forcing evacuation of park visitors; the river eventually flowed around the slide and washed out a major park road (Solomon, 1995). These events illustrate landslide damage to buildings, transportation routes, and utilities either directly from ground displacement or indirectly from associated flooding. Avoidance of landslide-prone areas is one prudent measure for landslide-hazard reduction, but engineering techniques can stabilize slopes and ensure that site grading and development do not decrease slope stability.

Slope steepness is a primary factor in determining landslide susceptibility. When other conditions are identical, steeper slopes are more susceptible to landsliding. However, additional factors influence landslide susceptibility and, under certain conditions, can result in a greater landslide susceptibility for some gentler slopes. Rocks containing low-strength, moisture-sensitive shale or clay, and unconsolidated deposits containing silt or clay, are the geologic materials most susceptible to landsliding. Other factors important in determining landslide susceptibility include: (1) ground-water conditions; (2) the presence of springs or surface water; (3) active stream incision, bank erosion, or undercutting; and (4) the orientation of planar features such as bedding, joints, faults, or the bedrock-soil interface.

Many landslides in the Springdale area, including the two largest landslides, occurred during Pleistocene time (1.6 million to 10,000 years ago). The largest landslide near Springdale is the Eagle Crags landslide, south of the East Fork of the Virgin River, with a volume of about 180 million cubic yards (140 million m^3)(Shroder, 1971). The next largest landslide near Sringdale is the Johnson Mountain landslide, northeast of the intersection of the North and East Forks of the Virgin River, with a volume of about 65 million cubic yards (50 million m^3)(Shroder, 1971). In comparison, the volume of the 1992 Springdale landslide is small at 18 million cubic yards (14 million m^3)(Black and others, 1995), and the volume of the 1995 Zion National Park landslide is only 110,000 cubic yards (84,000 m^3)(Solomon, 1995).

The Pleistocene climate in Utah was wetter than the modern climate, and elevated pore-water pressures in the soil and rock contributed to landsliding. Although some of the slopes that failed during Pleistocene time may be relatively stable now, old landslides can be particularly susceptible to partial reactivation because of conditions such as increased permeability in the displaced soil or rock mass and established, weakened failure planes. This process of reactivation is particularly evident in Zion National Park. The 1995 Zion National Park landslide is the latest in a series of small, historical slope failures, first recorded in 1923 and 1941 (Grater, 1945), in a larger prehistoric landslide that blocked the canyon about 4,000 years ago (Hamilton, 1984). Other reactivations have undoubtedly occurred but were not recorded.

USE OF THIS MAP

This map should be used as a tool for planning new development. The map will be most effective if used early in the planning process to identify the need for landslide-hazard studies. The relative landslide hazard shown on this map consists of three categories: low (designated on the map with an "L"), moderate ("M"), and high ("H"). The categories indicate the need for further study prior to development and the level of detail when further study is recommended (see table in map explanation). For development within moderate- and high-hazard areas, site-specific hazard studies are recommended prior to new construction. Cooperatively funded studies of subdivisions or groups of lots may be the most cost-effective means of hazard evaluation in large areas of moderate or high hazard.

This map is at a regional scale and the map-unit boundaries are approximate. Although the map can be used to gain an understanding of the potential for landslides in a given area, **it is not designed to replace site-specific studies performed by qualified professionals** (engineering geologists and geotechnical engineers) to evaluate the hazard and, if necessary, recommend hazard-reduction measures. Because of the relatively small scale of the map, the possibility exists that some small moderate- and high-hazard areas are not shown. Site-specific studies are therefore recommended for essential facilities, critical lifelines, and special- and high-occupancy buildings even in low-hazard areas.

The criteria used to define the relative landslide hazard were developed by analyzing failed geologic units, slope inclinations, and ages of existing landslides. Areas of artificial fill, such as imported material used for building foundations and road beds, were evaluated using the properties of the underlying native rock and soil. A critical slope value assigned to each geologic unit represents the inclination above which slope failures have typically occurred. Lower critical slope-inclination values correspond to higher landslide susceptibilities. The critical slope-inclination values used to derive the relative-hazard zones on this map range from 25 percent (14 degrees) to 65 percent (33 degrees). Landslides estimated to have occurred during the past 5,000 years (late Holocene time) represent slope failures under climatic conditions similar to the present and deposits with less time to reach a stable state of equilibrium; these younger landslides were differentiated from older landslides to indicate the relative potential for landslide reactivation within the high category of relative landslide hazard. Landslides of late Holocene age (young) are designated on the map with a "y" and landslides of pre-late Holocene age (old) are designated with an "o". Landslides were identified in this study from geologic mapping, aerial-photograph interpretation, review of existing geological and geotechnical reports, and field reconnaissance.

A low landslide hazard exists where slope inclination is less than the selected critical value and there is no evidence of previous landsliding (map unit L). **Low-hazard areas are common in the Virgin River flood plain, on the Rockville Bench in southwest Springdale, on sandstone ridges west and east of Springdale, and on scattered terraces between the flood plain and ridges.** Site-specific geotechnical studies of landslide hazard will usually not be warranted on sites within map unit L, except for essential facilities (for example, police and fire stations), critical lifelines (for example, main roads, trunk water lines, and utility corridors), and special- and high-occupancy buildings (for example, schools and hospitals).

A moderate landslide hazard exists where slope inclination is greater than the selected critical value and there is no evidence of previous landsliding (map unit M), and where slope inclination is less than the selected critical value but there is evidence of previous old landsliding (map unit M_o). **Moderate-hazard areas are common on slopes adjacent to the Virgin River flood plain.** Site-specific, reconnaissance-level geologic studies and, in some cases, preliminary geotechnical-engineering studies of landslide hazard are recommended prior to permitting development on sites within map units M and M_o. Depending on the results of these studies, some sites may require a detailed, quantitative geotechnical-engineering slope-stability analysis to adequately evaluate the hazard and develop hazard-reduction measures. Detailed analyses are most probable in areas of previous landslides (map unit M_o).

A high landslide hazard exists regardless of slope inclination where there is evidence of previous young landsliding (map unit H_y), and where slope inclination is greater than the selected critical value and there is evidence of previous old landsliding (map unit H_o). **High-hazard areas are common on slopes underlain by landslide debris adjacent to the Virgin River flood plain, particularly on the Johnson Mountain and 1992 Springdale landslides.** Site-specific geologic and preliminary geotechnical-engineering studies may in some cases be adequate to evaluate the hazard on sites within map units H_y and H_o. However, detailed, quantitative geotechnical-engineering slope-stability analyses will likely be necessary to evaluate the hazard and develop hazard-reduction measures prior to development within these high-hazard areas. Detailed analyses are most probable in areas of young landslides (map unit H_y).

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Criteria for Relative Landslide Hazard Classification and Recommended Requirements for Site-Specific Investigations

RELATIVE HAZARD	MAP UNIT	CRITERIA				RECOMMENDED SITE-SPECIFIC STUDIES
		PREVIOUS LANDSLIDES[1]		SLOPE[2]		
		Old	Young	<CV	≥CV	
Low	L			X		None (except for essential facilities, critical lifelines, and special- and high-occupancy buildings, where recommendations for moderate hazard apply)
Moderate	M				X	Geologic and, in some cases, preliminary geotechnical-engineering evaluation; detailed, quantitative geotechnical-engineering slope-stability analysis may be necessary[3]
	M_o	X		X		
High	H_o	X			X	Geologic and preliminary geotechnical-engineering evaluation; detailed, quantitative geotechnical-engineering slope-stability analysis likely necessary[3]
	H_y		X	X	X	

[1]Old - older than 5,000 years; Young - during the last 5,000 years.
[2]CV - critical slope-inclination value.
[3]Geologic and geotechnical evaluations of sites on large landslides that extend offsite should include study of the offsite parts of the landslide; cooperatively funded studies of subdivisions or groups of lots may be most cost-effective.

Base from Springdale West and Springdale East, Utah, USGS 7.5-minute topographic quadrangle maps.
Drafted by B.H. Mayes

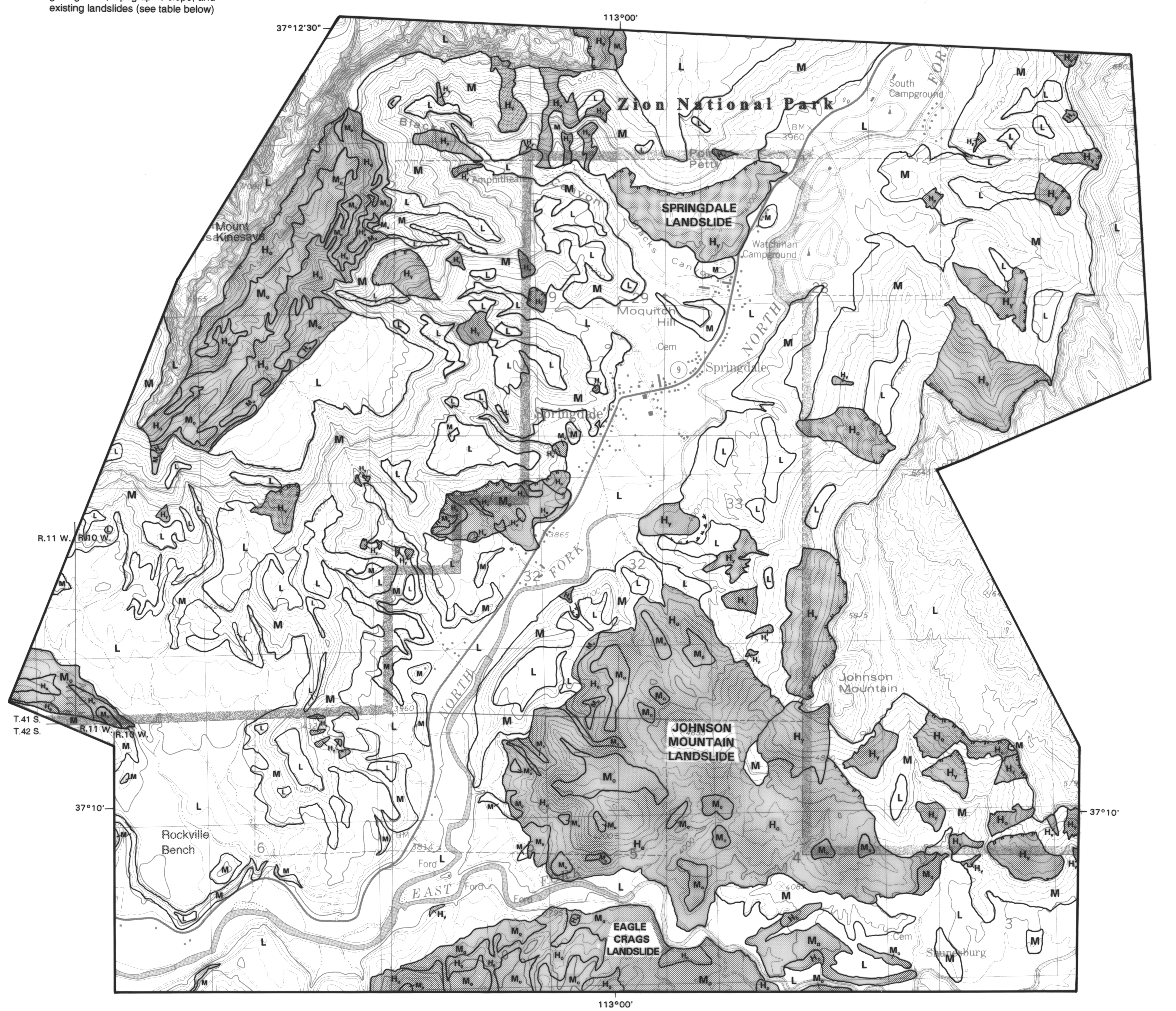
EXPLANATION

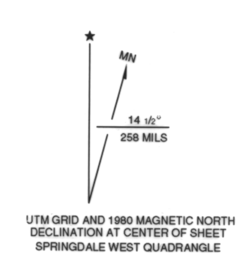
Main scarp of landslide, dashed where approximate

Landslide deposit
y, young (younger than 5,000 years)
o, old (older than 5,000 years)

L, M, H — Relative landslide hazard, based on geologic unit, topographic slope, and existing landslides (see table below)

Maps in this folio:





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1 0.5 0 1 KILOMETER

CONTOUR INTERVALS 40 AND 80 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

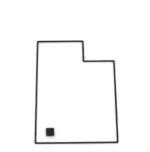

PLATE 1

LANDSLIDE HAZARD, SPRINGDALE, WASHINGTON COUNTY, UTAH

Barry J. Solomon
1996

DISCUSSION

This map shows areas where flood hazards and problem soils may exist, and indicates where further study is recommended prior to development. Recommended requirements for site-specific investigations are summarized in the map-explanation table.

Flood Hazards

Stream flooding, alluvial-fan flooding and debris flows, and dam-failure inundation are potential hazards in the Springdale area. Stream floods occur when the volume of flow exceeds the confines of the normal stream channel. Alluvial-fan floods occur when streams leave their main constricted channel at canyon mouths and flood surfaces and ephemeral channels of alluvial fans along the mountain front. Dam-failure inundation occurs when water is unintentionally released from a body of water confined by an engineered structure. Hazards associated with flooding include loss of life and property damage from drowning, high-velocity impact, erosion, or burial.

Stream flooding is typically associated with seasonal snowmelt and cloudburst rainstorms, and can accompany intentional releases from dams during periods of heavy runoff. Snowmelt floods are somewhat predictable because flood levels depend on the volume of snow in the mountains and the rate of temperature increase. However, cloudburst rainstorms can occur with little warning and account for localized but very destructive flooding. The Springdale area has experienced many cloudburst floods in historical times, including floods in 1920, 1930, 1954, 1961, 1966, and 1982 (Woolley, 1946; Butler and Marsell, 1972). In the 1966 flood, peak discharge of the Virgin River at many locations may have exceeded the 100-year flood level.

Alluvial-fan flooding is characterized by little advance warning and unpredictable flow paths. Floodwaters on alluvial fans commonly contain large amounts of sediment, including cobbles and boulders. As the proportion of sediment increases, and as the floodwaters incorporate debris from the flow path, alluvial-fan floods can grade into **debris flows** which have a consistency of a muddy slurry much like wet concrete. Alluvial-fan floods and debris flows are typically found on Holocene-age (0-10,000 years old) alluvial fans, which owe their existence to repeated deposition of sediment at the mountain front during these floods and debris flows. A recent episode of alluvial-fan flooding in Springdale resulted from a cloudburst storm in September 1983. Flood waters washed debris from Blacks Canyon and the adjacent canyon to the south along Paradise Road, pushing boulders and mud to the center of town and damaging several buildings and utility lines. Damage in Springdale was estimated at $1.2 million (Kaliser, 1989).

Dam-failure flooding may occur with little warning, and its severity depends on the size of the reservoir and the extent of failure. Only eight of 33 dam failures documented in Utah prior to 1984 were complete failures; most were due to overtopping and/or erosion around spillways and outlets during floods (Harty and Christenson, 1988). Although dam failures have many causes, the most common cause is structural and foundation failures resulting from piping (subsurface erosion of fine-grained sediment by ground water) (Dewsnup, 1987). Dams may also be vulnerable to failure during earthquakes. Relatively large dams are less prone to failure than small dams because of more rigorous design, construction, and inspection standards. Springdale is downstream of two dams: (1) Kolob Dam, 18 miles (29 km) north of Springdale on Kolob Creek, which drains into the North Fork of the Virgin River; and (2) South Creek Dam, 3 miles (5 km) south of Springdale on South Creek, which drains into the East Fork of the Virgin River.

Avoiding areas subject to flood hazards is an **effective means of hazard reduction**. However, for existing development on alluvial fans or flood plains, avoidance is not possible. Other techniques can be used to reduce hazards from stream floods and debris flows, including source-area stabilization, engineered protective structures, flood warnings, and flood proofing. Proper land use on flood plains will help reduce damage from dam-failure inundation to some extent, but the principal means of hazard reduction is emergency-response planning.

Problem Soils

Collapsible, expansive, and gypsiferous soils, and soil that is subject to piping, are present in the Springdale area. These soils, included under the broad category of problem soils, are susceptible to volumetric change, collapse, subsidence, erosion, or dissolution. Problem soils can cause engineering problems and should be evaluated prior to development.

Collapsible soils are subject to volume reductions that can damage structures by differential settlement. Collapse is generally initiated by human application of water to a susceptible deposit. Landscaping requiring irrigation is the most common triggering mechanism, but others include crop irrigation, water impoundment, alterations to natural drainage, leaking buried water and sewer lines, or wastewater disposal in soil absorption systems. The dry climate of southwestern Utah provides good conditions for development of collapsible soil. Such soil has been reported in Springdale (Ashland, 1996; Delta Geotechnical Consultants, Inc., 1995), and approximately $3 million in damage to public and private structures has been attributed to collapsible soil in Cedar City, about 35 miles (55 km) north of Springdale (Kaliser, 1978).

Expansive soils are clay-rich deposits that expand and contract with changes in moisture content. These soils can crack foundations, plug septic-tank soil-absorption systems, and promote landsliding. Sidewalks, roads, buried utilities, and slabs-on-grade are also susceptible to cracking and damage due to differential expansion and contraction of underlying material. Single-family homes are particularly susceptible to expansive soil because foundation loads may be less than the expansive pressures caused by the swelling material, making them subject to heave. Water from sprinkler systems and runoff from roofs and roads may increase soil moisture and initiate soil expansion. Expansive soils are the most common problem soils in Utah. Extensive damage is reported to structures built on these soils in the St. George area (Mulvey, 1992), 30 miles (50 km) southwest of Springdale, and expansive soils are noted in geotechnical reports for sites in Springdale (see, for example, Kaliser, 1975; Delta Geotechnical Consultants, Inc., 1995).

Gypsiferous soils are gypsum-rich deposits that have the potential to damage foundations by settlement, subsidence, collapse, or chemical reaction. Gypsum, a soluble mineral, may dissolve when wetted by irrigation for crops or landscaping, or by water from wastewater-disposal systems. When dissolved, settlement and land subsidence may occur due to loss of internal structure and volume. In some cases, large underground solution cavities may develop and collapse, forming circular depressions called sinkholes. Gypsum is also a weak material with low bearing strength. Gypsum weathers to form sulfuric acid and sulfate. These compounds may react with certain types of cement, weakening foundations by damaging the exterior surface. Gypsiferous soil derived from erosion of gypsum-rich rock is common in southwestern Utah, particularly along the base of the Hurricane Cliffs 15 miles (25 km) west of Springdale (Mulvey, 1992). Similar rock is found in the Springdale area.

Piping is a common process in arid climates where fine-grained, uncemented, unconsolidated deposits are incised by streams. Ground water moves through the permeable deposits and exits at a free face (commonly an eroded stream bank). Fine grains of soil (silt and clay) removed by this process leave voids that enlarge and coalesce into conduits (pipes). As the pipe size increases, support for its walls and roof is removed, causing eventual collapse. Erosion along a line of interconnected collapse features may form gullies. Piping can cause damage to any overlying structure. In areas where piping is common, roads are most frequently damaged because they commonly parallel stream drainages and cross-cut numerous pipes. Irrigation of cropland adjacent to incised drainages may also cause piping. Earthfill structures such as dams may be susceptible to piping, and piping of fine-grained embankment materials at the base of Quail Creek dike, 21 miles (34 km) west of Springdale, contributed to its failure in 1989 (James and others, 1989). In the Springdale area, evidence of piping was found adjacent to stream channels in Blacks Canyon and the canyon to the south, and soils susceptible to piping are expected in other canyons nearby.

Avoidance, moisture control, and various engineering techniques are **effective measures to reduce hazards** related to problem soils. Engineering techniques to reduce the potential for damage from collapsible soil include presoaking, removal, mechanical compaction, and special foundation design. The best method to reduce the hazard from expansive soil is to restrict changes in water content through proper design of drainage, supplemented by appropriate foundation design if necessary. Damage to structures from gypsiferous soil can also be limited by modifying drainage, supplemented by the use of appropriate concrete and coatings to protect the foundation from deterioration. Damage caused by piping can be reduced by controlling drainage in susceptible soil through the use of culverts, closed conduits, and lined drainage ditches, and by limiting the amount of agricultural irrigation along incised stream channels.

USE OF THIS MAP

This map should be used as a tool for planning new development. The map will be most effective if used early in the planning process to identify the need for hazard studies on a development-wide scale. The potential hazard areas on the map indicate the need for further study prior to development (see table in map explanation). For development within hazardous areas, site-specific hazard studies are recommended prior to new construction. Cooperatively funded studies of subdivisions or groups of lots may be the most cost-effective means of hazard evaluation in large hazardous areas.

This map is at a regional scale and the map-unit boundaries are approximate. Although the map can be used to gain an understanding of the potential for flood hazards and problem soils in a given area, **it is not designed to replace site-specific studies performed by qualified professionals** (engineering geologists, geotechnical engineers, and hydrologists) to evaluate the hazard and, if necessary, recommend hazard-reduction measures. Because of the relatively small scale of the map, the possibility exists that some small hazardous areas are not shown. Site-specific studies are therefore recommended for essential facilities, critical lifelines, and special- and high-occupancy buildings even outside the delineated hazard areas.

Flood Hazards

This map shows 100-year flood plains as delineated by the Federal Emergency Management Agency (FEMA), as well as my approximated extension of those flood plains into an area of southern Springdale not mapped by FEMA. The Federal Insurance Administration's National Flood Insurance Program has established guidelines for development within the FEMA 100-year flood plains. Prior to development in the flood-plain extension, studies should define the 100-year flood plain within which FEMA guidelines should be applied. Flooding may also occur in undesignated areas not shown on the map along smaller drainages.

The map shows boundaries of Holocene alluvial fans, which are areas where alluvial-fan flooding and debris flows may occur. The potential hazard may increase if the vegetation in drainage basins is damaged by wildfire, grazing, or development. Site-specific studies should address parts of the fan surface that would be subject to channelized flow versus sheet flow, the potential for flooding and debris flows based on drainage-basin and channel conditions above the fan, and the effect of existing upstream structures that might divert or contain floods or flows.

Dam-failure inundation maps are available for Kolob and South Creek Dams as part of emergency-action plans (Alpha Engineering Co., 1991; Bingham Engineering, 1994) on file with the Utah Division of Water Rights, Dam Safety Section. The information in these documents should be used for land-use and emergency-response planning.

Problem Soils

Hazard zones associated with collapsible, expansive, and gypsiferous soils are shown on this map, but hazard zones associated with piping cannot be accurately delineated at the map scale and are not shown. Areas most susceptible to collapsible soils are along the mountain front where alluvial-fan deposits contain fine-grained sediment derived from shale and mudstone. Areas most susceptible to expansive soils are underlain by shale and mudstone, and their relative susceptibility depends on the geologic unit. Areas of gypsiferous soils are underlain by rocks containing gypsum as a primary component; gypsum may also occur in other rocks as a secondary mineral leached from surficial layers, but this gypsum is usually not in sufficient concentration to pose a hazard. The potential for collapsible, expansive, and gypsiferous soils, as well as piping and other soil-engineering properties, should be evaluated in a standard soil-foundation investigation prior to development.

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Recommended Requirements for Site-Specific Investigations of Mapped Potential Hazards

Hazard	Potential hazard area[1]	DEVELOPMENT TYPE			
		Essential facilities, critical lifelines, special- and high-occupancy buildings	Industrial and commercial buildings (other than high-occupancy	Residential subdivisions	Residential single lots
Stream flooding	100-year flood				
	In	Yes	Yes	Yes	Yes
	Out	Yes	No	No	No
Alluvial-fan flooding/ debris flows	AF				
	In	Yes	Yes[2]	Yes[2]	Yes[2]
	Out	Yes	No	No	No
Collapsible soils	AF				
	In	Yes	Yes	Yes	Yes
	Out	Yes	No	No	No
Expansive soils	X				
	High	Yes	Yes	Yes	Yes
	Moderate	Yes	Yes	Yes	Yes
	Low	Yes	No	No	No
Gypsiferous soils	G				
	In	Yes	Yes	Yes	Yes
	Out	Yes	No	No	No

[1]Recommended requirements are for site-specific investigations if sites are inside (In) or outside (Out) designated hazard areas or are in designated relative-hazard zones (High, Moderate, or Low).

[2]If a debris basin is present above the site, a site-specific investigation for debris flows or debris floods is not required; local officials should be contacted regarding debris-basin adequacy.

Base from Springdale West and Springdale East, Utah, USGS 7.5-minute topographic quadrangle maps.
Drafted by B.H. Mayes

EXPLANATION

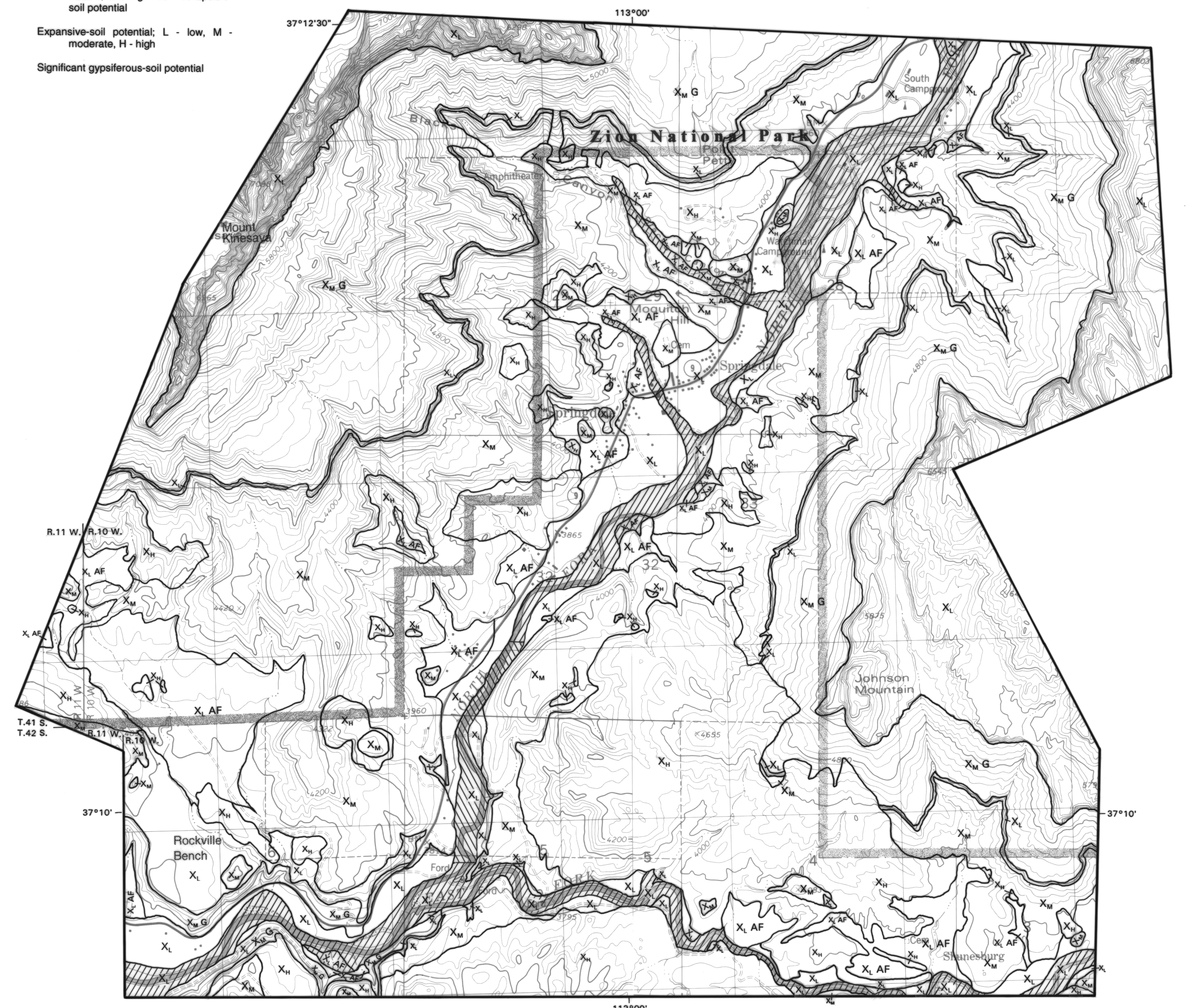
Stream-flood hazard

- FEMA 100-year flood plain
- Approximate extension of 100-year flood plain into area not mapped by FEMA

AF — Alluvial-fan flood hazard, debris-flow hazard, and significant collapsible-soil potential

X_L — Expansive-soil potential; L - low, M - moderate, H - high

G — Significant gypsiferous-soil potential



SCALE 1:14,400

1 0.5 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 0.5 0 1 KILOMETER

CONTOUR INTERVALS 40 AND 80 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

UTM GRID AND 1980 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

MAP LOCATION

PLATE 2

FLOOD HAZARDS AND PROBLEM SOILS, SPRINGDALE, WASHINGTON COUNTY, UTAH

Barry J. Solomon

1996

DISCUSSION

This map shows areas where earthquake hazards, shallow ground water, rock-fall hazards, and indoor-radon hazards may exist, and indicates where further study is recommended prior to development. Recommended requirements for site-specific investigations are summarized in the map-explanation table.

Earthquake Hazards

Potential earthquake hazards in Springdale include ground shaking, landsliding, rock falls, and liquefaction. Ground shaking is generally the most widespread and frequent earthquake hazard, and is responsible for most earthquake-related damage. Springdale is susceptible to ground shaking both from nearby earthquakes and from more distant earthquakes, but local historical earthquakes are rare and of low intensity. The strongest earthquakes in southwestern Utah will likely be associated with the Hurricane fault, 16 miles (26 km) west of Springdale, and the Sevier fault, 18 miles (29 km) east of Springdale. The Hurricane fault was the probable source of the 1992 St. George earthquake (Pechmann and others, 1995). **Ground shaking cannot be avoided**, but resulting loss of life and damage to structures can be reduced by meeting the requirements for earthquake-resistant design and construction specified in seismic provisions of the Uniform Building Code (UBC; International Conference of Building Officials, 1994). The UBC defines two factors, Z and S, to quantify the minimum level of ground shaking that structures must be designed to withstand without collapse. The seismic zone factor (Z) attempts to quantify ground motions on rock; Springdale is in UBC seismic zone 2B. The site factor (S) attempts to quantify the effects of near-surface sediments on the ground motions. Regional geology suggests S_1-type site conditions, indicating a site factor of 1.0. Site-specific geologic conditions must be evaluated to accurately determine this factor.

Earthquake-induced landslides and rock falls are significant hazards in Springdale, particularly if an earthquake occurs in the springtime or during other wet periods. A landslide in Springdale was the most damaging result of the 1992 St. George earthquake, and numerous rock falls were observed along steep cliffs in the Springdale area during the earthquake. The Springdale landslide destroyed two water tanks, several storage buildings, and three homes; ruptured buried and above-ground utilities; and disrupted transportation on State Route 9 leading into the southern entrance of Zion National Park (Black and others, 1995). Earthquake-induced landslides and rock falls will likely occur in moderate- and high-hazard areas shown on the landslide (plate 1) and rock-fall (this plate) hazard maps in this folio. General discussions of the landslide and rock-fall hazards and hazard-reduction measures are included on the hazard maps.

Liquefaction occurs when earthquake ground shaking causes certain soils to behave like a liquid. Liquefaction most commonly occurs in areas of shallow ground water and loose sandy soils. Such soils can lose their ability to support structures and can, in some cases, move downslope. Structures that are particularly sensitive to liquefaction-induced ground failure include buildings with shallow foundations, railway lines, highways and bridges, buried structures, dams, canals, retaining walls, utility poles, and towers. A measure of the potential severity of the liquefaction hazard is the Liquefaction Severity Index (LSI). The LSI expresses the potential maximum magnitude of differential deformation, in inches, resulting from liquefaction of susceptible soils. Probabilistic values of the LSI represent a 1-in-10 chance that the maximum deformation will occur during various exposure times; the LSI is mapped in Utah for exposure times of 10, 50, 250, and 1000 years (Mabey and Youd, 1989). Areas susceptible to liquefaction need not be avoided because **various foundation designs and subgrade treatments are available to reduce liquefaction hazards.** Although the cost of some hazard-reduction techniques may be high for single-family dwellings, liquefaction is generally not a life-threatening hazard in these structures.

Shallow Ground Water

Ground water is water in saturated zones beneath the land surface. Ground water fills fractures and pore spaces in rocks and voids between grains in unconsolidated deposits of clay, silt, sand, and gravel. **Ground water is considered shallow when the water table is within 30 feet (10 m) of the ground surface** (Hecker and others, 1988). Shallow ground water in most rock poses a relatively insignificant hazard because foundations and conventional waste-water disposal systems in rock are uncommon and foundation stability in fractured, competent rock is not appreciably reduced by saturated conditions. However, construction in areas of unconsolidated sediments and less competent rock is subject to various hazards associated with shallow ground water.

Shallow-ground-water hazards include flooding of subsurface facilities; destabilization of foundations, excavations, or slopes; surface flooding; and liquefaction of soils during earthquakes. Flooding in basements, foundations, and excavations due to shallow ground water is generally only a hazard when the saturated zone is within the depth to which most buildings are excavated, usually 10 feet (3 m) or less. Shallow ground water can also damage underground utilities and septic-tank soil-absorption systems and can inundate landfills and waste dumps, contaminating aquifers and wells. A rising water table can cause damage to previously unaffected facilities and, if ground water rises to the surface, can cause surface flooding. The depth to ground water can fluctuate as the result of such factors as seasonal precipitation, irrigation, long-term climate change, and earthquakes. Liquefaction during earthquakes, and related ground failure, may occur in susceptible soils where the depth to ground water is less than 30 feet (10 m).

Avoidance of potential shallow-ground-water areas is an effective method of reducing hazards, but is not always possible. **Construction techniques to reduce or eliminate the adverse effects of ground-water flooding are available** and include water proofing, drainage systems, slab-on-grade or pile foundations, and the addition of fill to increase building elevation. Pumping is an expensive and unreliable technique for permanently lowering a water table, but may be used during construction. Basement sump pumps are usually effective for individual homes.

Rock-Fall Hazards

Rock fall is a natural erosional process in mountainous areas. As mountain slopes are developed, the risk from falling rocks increases. Rock falls can damage structures, roadways, and vehicles and may pose a significant safety threat.

Heavy precipitation and alternating freeze-thaw conditions often trigger rock falls. Water from precipitation weakens supporting clayey rock and may reduce the strength necessary to bear the weight of overlying sandstone or boulders, or causes the clay to expand and loosen rock. Water in sandstone fractures and beneath boulders also expands during freezing, and may move the rock enough to initiate a rock fall. In addition, **rock fall is the most common type of slope instability caused by earthquakes.** The September 1992 magnitude 5.8 St. George earthquake caused numerous rock falls that resulted in minor damage, and rock falls may occur in earthquakes as small as magnitude 4.0. Rock falls are hazardous because a large rock mass traveling at high speed can damage structures and increase the risk to personal safety. Sandstone slabs shed downslope during toppling failures may weigh several tons and travel at speeds of 70 miles per hour (mph)(110 km/h) or more; smaller individual boulders falling off cliff edges may weigh several hundred pounds and travel at speeds of 50 to 60 mph (80-100 km/h)(Stover and Rogers, 1983).

Techniques for reducing rock-fall hazards include rock stabilization, engineered structures, or modification of exposed structures or facilities. Rock-stabilization techniques are physical methods of reducing the hazard at its source. Engineered structures may stop, deflect, retard, or retain falling rocks. Strenghening a structure to withstand impact is an example of modifying structures at risk.

Indoor-Radon Hazards

Radon is an odorless, tasteless, and colorless radioactive gas. The most common type of radon is a naturally occurring product of the radioactive decay of uranium found in small concentrations in nearly all soil and rock. Because radon is a gas, it is highly mobile and can enter buildings through small foundation cracks and other penetrations such as utility pipes. Although outdoor radon concentrations never reach dangerous levels because it dissipates the gas, indoor radon concentrations may reach hazardous levels because of poor air circulation in buildings. Breathing any level of radon over time increases a person's risk of lung cancer, but long-term exposure to low radon levels is generally considered a small health risk. Smoking increases the health risk due to radon. The U.S. Environmental Protection Agency (EPA) recommends that action be taken to reduce indoor-radon levels when they exceed 4 picocuries of radon per liter of air (pCi/L)(148 Becquerels per cubic meter [Bq/m^3]).

Several geologic factors affect the indoor-radon hazard. A primary geologic prerequisite is that the building must be built on soil or rock that contains a source of radon. Granite, metamorphic rocks, some volcanic rocks and shale, and soils derived from these rocks are generally associated with indoor-radon hazards. If a radon source is present, easy movement of radon through the soil and into the overlying building is enhanced by high soil permeability. Water saturation of soil inhibits radon movement by dissolving radon and restricting its flow through foundation soil. Although the influence of geologic factors can be estimated, the influence of **non-geologic factors** such as occupant lifestyle and home construction methods is more variable. As a result, indoor-radon levels fluctuate and 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.

Techniques for reducing indoor-radon levels in existing buildings are included in two categories: (1) preventing radon from entering the building, and (2) removing radon or its decay products from the building after entry. The specific technique chosen depends on the initial radon concentration, building design, and building construction. Immediate actions to reduce indoor-radon levels can be done quickly with a minimum of expense, but they are not long-term solutions. Immediate actions include discouraging smoking inside a home, spending less time in areas of high radon concentration, and improving ventilation by opening windows and using fans. Permanent actions to reduce radon often require professional assistance to identify radon-entry routes and perform diagnostic testing to aid in the selection of the most effective radon-reduction technique. **New buildings** may incorporate methods to restrict radon entry, and features can also be incorporated during construction that facilitate radon removal after home completion if prevention methods are inadequate. If professional assistance is required to test for radon or reduce the indoor-radon hazard, **choose a contractor who has been certified by the EPA**; these contractors pass comprehensive exams and agree to follow rigorous standards of professional conduct.

USE OF THIS MAP

This map should be used as a tool for land-use planning. The map will be most effective if used early in the planning process to identify the need for hazard studies on a development-wide scale. The potential hazard areas on the map indicate the need for further study prior to development (see table in map explanation). For development in hazardous areas, site-specific hazard studies are recommended prior to new construction. Cooperatively funded studies of subdivisions or groups of lots may be the most cost-effective means of hazard evaluation in large hazardous areas.

This map is at a regional scale and the map-unit boundaries are approximate. Although the map can be used to gain an understanding of the potential for liquefaction, shallow ground water, rock-fall, and indoor-radon hazards in a given area, **it is not designed to replace site-specific studies performed by qualified professionals** (engineering geologists, geotechnical engineers, and hydrologists) to evaluate the hazard and, if necessary, recommend hazard-reduction measures. Because of the relatively small scale of the map, the possibility exists that some small hazardous areas are not shown. Site-specific studies are therefore recommended for essential facilities, critical lifelines, and special- and high-occupancy buildings even outside the delineated hazard areas.

Earthquake Hazards

Hazard zones associated with **ground shaking and earthquake-induced landslides** are not shown on the map, as noted in the "Discussion." Standard soil-foundation reports should provide data for UBC site factors used in seismic design. Recommendations for landslide-hazard investigations are included on the landslide-hazard map of this folio (plate 1).

The map shows a hazard zone for **liquefaction** defined by the Liquefaction Severity Index (LSI). In Springdale, the LSI is less than 5 (little damage) for exposure periods of 10 and 50 years, between 5 and 30 (moderate to severe damage) for an exposure period of 250 years, and greater than 30 (irreparable, severe damage) for an exposure period of 1,000 years. Because of the length of the exposure periods in which the LSI indicates a potential for moderate to severe damage, liquefaction in Springdale is mainly a significant hazard to essential facilities and special- and high-occupancy buildings constructed on susceptible soil. This soil is generally restricted to the shallow ground-water zone along the Virgin River and its North and East Forks. **Site-specific studies** should be performed for appropriate facilities (for example, hospitals, schools, and police and fire stations) in all areas to evaluate the liquefaction hazard and recommend hazard-reduction measures, but a liquefaction hazard is more likely in the mapped area of shallow ground water.

Shallow Ground Water

Information on ground-water depth was compiled from unpublished well-log data from the Utah Division of Water Rights. **Shallow ground water is less than 30 feet (10 m) deep, and commonly less than 10 feet (3 m) deep**, but a precise delineation of areas with ground water less than 10 feet (3 m) deep cannot be made at the map scale because of a lack of detailed well control. **Site-specific shallow ground-water studies** are recommended for all types of construction with subsurface facilities, particularly buildings with basements or using septic-tank soil-absorption fields, in areas where the water table is likely to be within 10 feet (3 m) of the ground surface. Site-specific studies should identify the highest ground-water level recorded or visible in sediments, the present ground-water level, and the highest expected water table as controlled by seasonal precipitation, irrigation, and long-term fluctuations.

Rock-Fall Hazards

Rock-fall-hazard zones in Springdale are defined by the distribution of sources for rock-fall fragments, distance from the source areas, and slope steepness. The trajectory a given rock fragment could follow is so unpredictable that it is impractical to delineate hazard zones based on the predicted trajectories from source areas. A **high rock-fall hazard** is present on sandstone cliffs on either side of the North Fork of the Virgin River, on a sandstone ledge along the Virgin River southwest of Springdale, and on steep slopes beneath the cliffs and ledge. Large slabs periodically detach from the sandstone outcrops, shatter, and shower rock fragments on the steep slopes below. Few rock fragments of significant size are retained on these slopes, and the fragments gain energy and momentum as they accelerate downslope. A **moderate rock-fall hazard** is present on more moderate slopes beneath the acceleration zone and on the Virgin River flood plain beneath the sandstone ledge. Colluvial boulders, landslide debris, and rock-fall fragments from past events may dislodge from the moderate slopes and, with rock fragments from the acceleration zone above, travel downslope. The majority of rocks travelling through this runout zone eventually come to rest in it. Although the slope of the Virgin River flood plain is much lower, a moderate rock-fall hazard is warranted from its proximity to the sandstone ledge. A **low rock-fall hazard** is present on nearly horizontal slopes in the flood plain of the North and East Forks of the Virgin River and on similar slopes in smaller side canyons. Rock-fall fragments rarely reach these areas and, when they do, quickly come to rest upon arrival.

Detailed, **site-specific rock-fall evaluations** are recommended for all construction in areas of high rock-fall hazard. Site investigations should define rock-fall sources and estimate runout paths and distances from each source. Physical evidence such as size, shape, and depth of burial of rock-fall sources, extent of rock-fragment accumulations below sources, slope geometry, damaged vegetation, and natural barriers are all important factors to be considered. Computer models are available to simulate runout. Site-specific, reconnaissance-level studies may in some cases be adequate to evaluate the hazard on sites within areas of moderate rock-fall hazard, but detailed studies may be necessary. In areas of low rock-fall hazard, site-specific rock-fall evaluations are only recommended for essential facilities and special- and high-occupancy buildings.

Indoor-Radon Hazards

Three categories of radon-hazard potential are mapped in Springdale: (1) high, areas where all geologic factors contribute to elevated indoor-radon levels; (2) moderate, areas where most geologic factors contribute to elevated indoor-radon levels; and (3) low, areas where most geologic factors do not contribute to elevated indoor-radon levels. A **high radon-hazard potential** is found on foothill slopes adjacent to the Virgin River and its North and East Forks. On these slopes ground water is deep, uranium levels are relatively high, and, although the predominant clay-rich bedrock is impermeable, the overlying granular colluvium is permeable. A **moderate radon-hazard potential** is found on the river flood plains where ground water is shallow, uranium levels are moderate, and the sediment is permeable. A **low radon-hazard potential** is found on higher slopes and cliffs where ground water is deep but either uranium levels are very low in permeable sandstone, or uranium levels are moderate in less permeable, finer grained bedrock.

Site investigations addressing indoor-radon hazards in existing buildings consist of testing indoor-radon concentrations. Although the radon-hazard map can be used to prioritize testing by indicating the urgency with which it should be undertaken, ultimately **all existing buildings should be tested. Site investigations addressing the potential for indoor-radon hazards in new construction are not cost-effective or recommended.** The radon-hazard map can be used to determine where **radon-resistant construction techniques should be considered for new construction**. The EPA believes that the use of passive radon control systems in areas of high radon-hazard potential, and the activation of those systems if necessitated by follow-up testing, is the best approach to achieving both significant radon-risk reduction and cost-effectiveness in construction of new homes (for descriptions of these systems, see U.S. Environmental Protection Agency, 1994). A passive system includes construction techniques that create physical barriers to radon entry, reduce the forces that draw radon into a building, and facilitate post-construction radon removal if the barrier techniques prove to be inadequate. Passive systems do not need the active participation of the occupant for operation or maintenance. The use of radon-resistant construction techniques may be appropriate in areas of moderate radon-hazard potential, but is generally not necessary in areas of low radon-hazard potential.

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Recommended Requirements for Site-Specific Investigations of Mapped Potential Hazards

Hazard	Potential hazard area[1]	DEVELOPMENT TYPE: Essential facilities, lifelines, special- and high-occupancy buildings	Industrial and commercial buildings (other than high-occupancy)	Residential subdivisions	Residential single lots
Liquefaction	LSI>5 for exposure period>250 years				
	In	Yes	No[2]	No[2]	No[2]
	Out	Yes	No	No	No
Shallow ground water	Depth<30 feet, commonly <10 feet				
	In	Yes	Yes	Yes	Yes
	Out	Yes	No	No	No
Rock fall	RF				
	High	Yes	Yes	Yes	Yes
	Moderate	Yes	Yes[3]	Yes[3]	Yes[3]
	Low	Yes	No	No	No
Indoor radon	RN				
	High	Yes[4]	Yes[4]	Yes[4]	Yes[4]
	Moderate	Yes[4]	Yes[4]	Yes[4]	Yes[4]
	Low	No	No	No	No

[1]Recommended requirements are for site-specific investigations if sites are inside (In) or outside (Out) designated hazard areas or are in designated relative-hazard zones (High, Moderate, or Low), except for the indoor-radon hazard (see note 4).

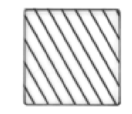
[2]Appropriate disclosure should be required.

[3]Site-specific, reconnaissance-level studies may be adequate, but detailed studies may be necessary.

[4]Recommended requirements are for the use of radon-resistant construction techniques in new construction; these techniques may be appropriate in areas of high to moderate radon-hazard potential, but their use is at owner discretion. Site investigations addressing the potential for indoor-radon hazards in new construction are not cost-effective or recommended. Site investigations addressing indoor-radon hazards in existing buildings consist of testing indoor-radon concentrations; all existing buildings should be tested.

Base from Springdale West and Springdale East, Utah, USGS 7.5-minute topographic quadrangle maps.
Drafted by B.H. Mayes

EXPLANATION



Liquefaction and shallow ground-water hazards

High relative liquefaction hazard

Ground-water depth less than 30 feet (10 m), commonly less than 10 feet (3 m)

RF_L Rock-fall hazard

Relative rock-fall hazard, based on source-area distribution, distance from source areas, and slope steepness; L - low, M - moderate, H - high

RN_L Indoor-radon hazard

Relative indoor-radon hazard, based on uranium concentration, permeability, and ground-water depth; L - low, M - moderate, H - high

Maps in this folio:

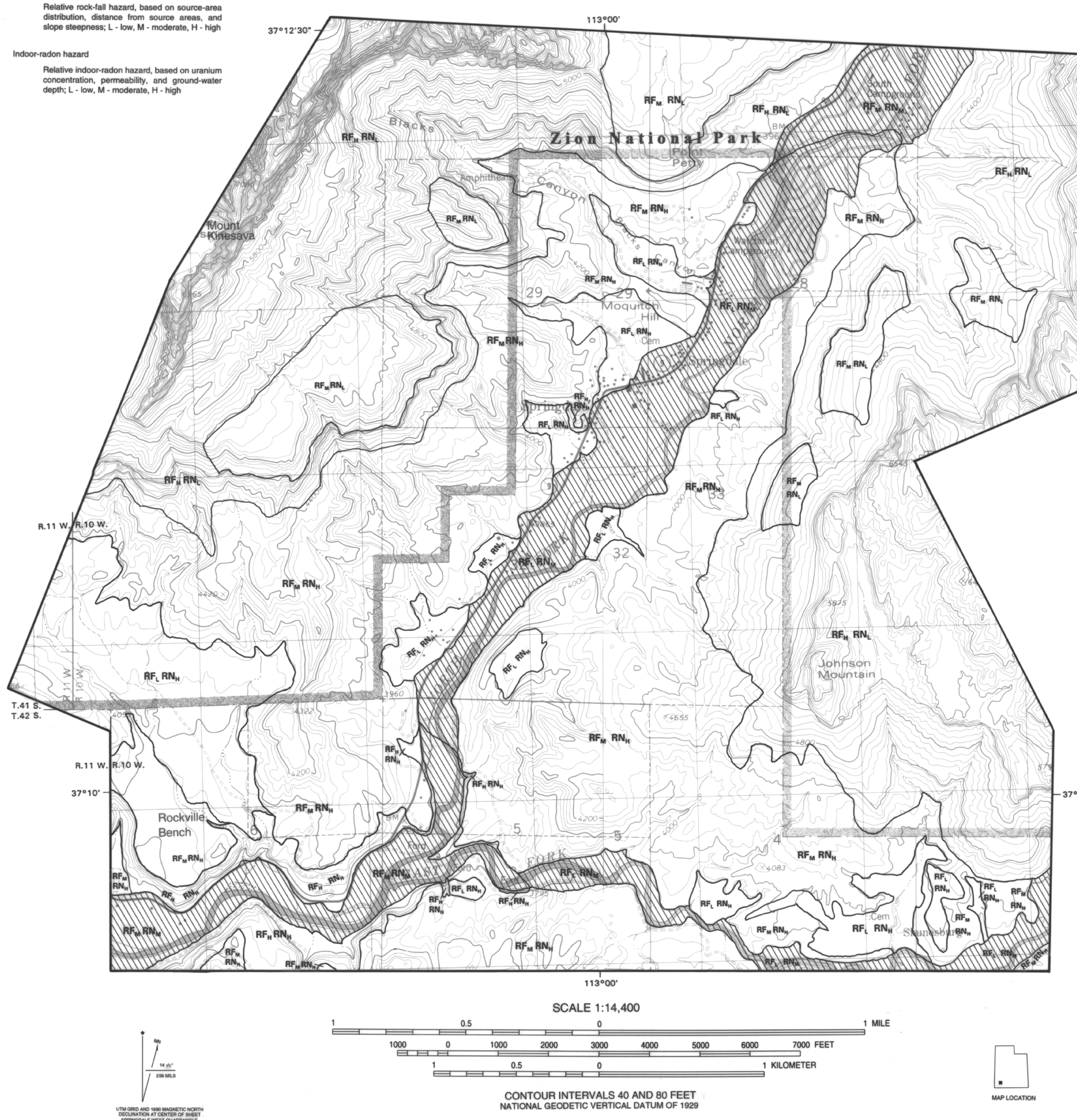


PLATE 3

EARTHQUAKE HAZARDS, SHALLOW GROUND WATER, ROCK-FALL HAZARD, AND INDOOR-RADON HAZARD, SPRINGDALE, WASHINGTON COUNTY, UTAH

Barry J. Solomon
1996

Maps in this folio:

- Landslide Hazard (Plate 1)
- Flood Hazards and Problem Soils (Plate 2)
- Earthquake Hazards, Shallow Ground Water, Rock-Fall Hazard, and Indoor-Radon Hazard (Plate 3)
- Suitability for Wastewater Disposal in Septic-Tank Soil-Absorption Systems (Plate 4)
- Geologic Map (Plate 5A)
- Description and Correlation of Map Units, Stratigraphic Column, and Geologic Cross Section (Plate 5B)

PLATE 4

SUITABILITY FOR WASTEWATER DISPOSAL IN SEPTIC-TANK SOIL-ABSORPTION SYSTEMS, SPRINGDALE, WASHINGTON COUNTY, UTAH

Barry J. Solomon

1996

DISCUSSION

This map shows areas of relative suitability for wastewater disposal in septic-tank soil-absorption (STSA) systems. When properly designed, constructed, and maintained, such systems are not a hazard to ground-water supplies, except for possible contamination by nitrate leached to the water table. Nitrate contamination can be controlled within acceptable limits by avoiding high-density developments with lot sizes less than one acre. Other than this consideration, a correlation between lot size and site suitability does not exist. **Conditions suitable for an STSA system should be proven on a lot, regardless of its size, before the system is installed.** The number of lots in a subdivision and their layout should then be based on the availability of suitable disposal sites, rather than on a predetermined minimum lot size.

Site characteristics critical to the proper functioning of an STSA system include soil type, depth to ground water, depth to bedrock, slope steepness and stability, and flood hazard. **Soils** with a high clay content seldom possess sufficient permeability to function properly in an STSA system, particularly if the clay minerals are expansive. Such soils may perform satisfactorily for a short time, but insufficient permeability eventually causes system failure as the soil becomes saturated, swells, and plugs. System failure may also be caused by physical damage associated with expansive and collapsible soil. If soils are too coarse grained and lack fine particles, permeabilities may be too high and filtering capability too low to effectively filter contaminants from the effluent. Under such conditions ground-water contamination is a concern. In areas where **ground water** is shallow, the potential for ground-water contamination is increased, as is the possibility of system saturation and failure. STSA systems installed in or just above **bedrock** may pollute ground water in rock aquifers with high fracture permeability and low filtering capability, or may fail in rock with low permeability. Surface seepage may result when STSA systems are installed on **steep slopes**, especially where impermeable soil horizons or caliche layers restrict the downward movement of the effluent and force it to migrate laterally to a slope face. STSA systems on potentially **unstable slopes** can destabilize the slopes by increasing soil moisture. In addition to destroying the STSA system, the resultant slope failure can damage other structures and property. The cumulative effects of many systems on a large, old, presently stable landslide may cause reactivation and a large-scale slope failure. **Flooding** presents a hazard to STSA systems because associated erosion can damage the system. Also, floodwaters infiltrating the ground may flood the system and cause failure, and may carry fine sand and silt into distribution lines, causing them to plug.

Geologic, hydrologic, and soil conditions in Springdale are variable and, as a result, the suitability for STSA systems also varies. Large areas are characterized by shallow or exposed bedrock, shallow ground water, and/or steep slopes. Other areas are generally suitable for STSA systems or have limiting conditions that are either localized or can be accomodated in system design.

USE OF THIS MAP

The relative STSA-system suitability consists of three categories: (I) generally suitable, (II) locally suitable, and (III) generally unsuitable. The mapped boundaries of the relative-suitability areas should be considered gradational, representing zones of transition rather than distinct boundaries.

The criteria used to define the relative-suitability categories are based on **Utah Department of Health regulations** adopted by the Southwest Utah Public Health Department. These regulations **must be followed when siting STSA systems**, regardless of the suitability category indicated on this map. Site conditions critical in establishing the categories are denoted on the map by qualifiers ("a" through "d") and geologic-hazard designations ("A", "F", and "L"), which are listed on the map explanation and in the map-explanation table. These conditions, and sources of data used to characterize them, include:

- collapsible soil from plate 2;
- seasonal ground-water depth from water wells, Utah Division of Water Rights, and from plate 3;
- depth to bedrock inferred from plate 5A;
- slope inclination from U.S. Geological Survey 7.5-minute topographic maps;
- alluvial-fan-flood- and debris-flow-hazard areas from plate 2;
- stream-flood-hazard areas from Federal Emergency Management Agency and Federal Insurance Administration maps and plate 2; and
- landslide-hazard areas from plate 1.

Soil percolation rates are also crucial for proper evaluation of STSA-system-site suitability. U.S. Soil Conservation Service information on soil percolation rates in Springdale is in insufficient detail for use as a factor in constructing this map. Soil percolation rates must be determined in site-specific investigations, regardless of the relative suitability category of the proposed site. Suitable percolation rates are generally expected in areas mapped as category "I" or "II".

In general, **a suitability designation of "I" indicates that site conditions are favorable for proper functioning of an STSA system**, and the risk of system failure due to geologic or hydrologic factors is low. However, all areas mapped as category I in Springdale are subject to hazards associated with collapsible soil, alluvial-fan flooding, or debris flows. Collapsible-soil hazards can be accomodated in STSA-system design and their presence does not necessarily restrict system siting. Alluvial-fan floods and debris flows are important hazards to consider when siting any facility, but they are short-term phenomena that should not seriously impact the operation of properly designed, constructed, and maintained STSA systems.

Areas designated as "II" and "III", respectively, have certain limiting conditions of progressively greater extent. For example, a map area designated as "IIc" indicates that shallow bedrock may be expected beneath parts of the area, but site-specific evaluations should find locally favorable sites underlain by deeper bedrock. In contrast, a map area designated as "IIIc" indicates that shallow bedrock should be expected beneath the entire area, and alternative methods of wastewater disposal will likely be necessary.

This map is intended for use as a tool to highlight possible geologic and hydrologic conditions that might affect the performance of STSA systems. It will be most effective if used to guide planning decisions regarding the suitability of particular areas for conventional STSA systems or alternative methods of wastewater disposal, such as mound systems, pressure-distribution systems, or sewers. The relative suitability for conventional STSA systems is based on geologic and hydrologic conditions important to system performance, and **does not reflect considerations such as aquifer recharge areas, proximity to ponds or streams, and STSA-system density.**

The map is at a regional scale and, although it can be used to determine the general suitability for STSA systems in a given area, it is not intended to provide information for design of on-site wastewater-disposal systems. Site-specific suitability evaluations performed by qualified professionals (engineering geologists, geotechnical engineers, and health department officials) are necessary prior to installation of any new STSA system. Such evaluations should include percolation tests; determination of depth to ground water, depth to bedrock, and topographic slope; soil testing for factors relevant to system design; and the proximity of the proposed system to ground-water recharge areas, surface water, drainage systems, and water-supply sources. Additionally, flood and landslide hazards should be evaluated in areas where those hazards are indicated on the map. Plates 1 (Landslide Hazard) and 2 (Flood Hazards and Problem Soils) of this map folio include discussions of these hazards and recommendations for hazard-evaluation studies. STSA systems may be feasible within some of these hazard areas with proper hazard-reduction measures or site modifications.

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EXPLANATION

Suitability:

I Generally suitable
II Locally suitable
III Generally unsuitable

Qualifiers*:

a Collapsible soil
b Depth to shallowest expected water table 0-4 feet
c Depth to bedrock 0-5 feet (includes bedrock blocks in landslides)
d Slope steeper than 25 percent

* Where present, shallow bedrock (qualifier "c") is the principal factor that limits the suitability of sites in suitability categories II or III and, although other qualifiers may apply, they are not noted.

Geologic Hazards:**

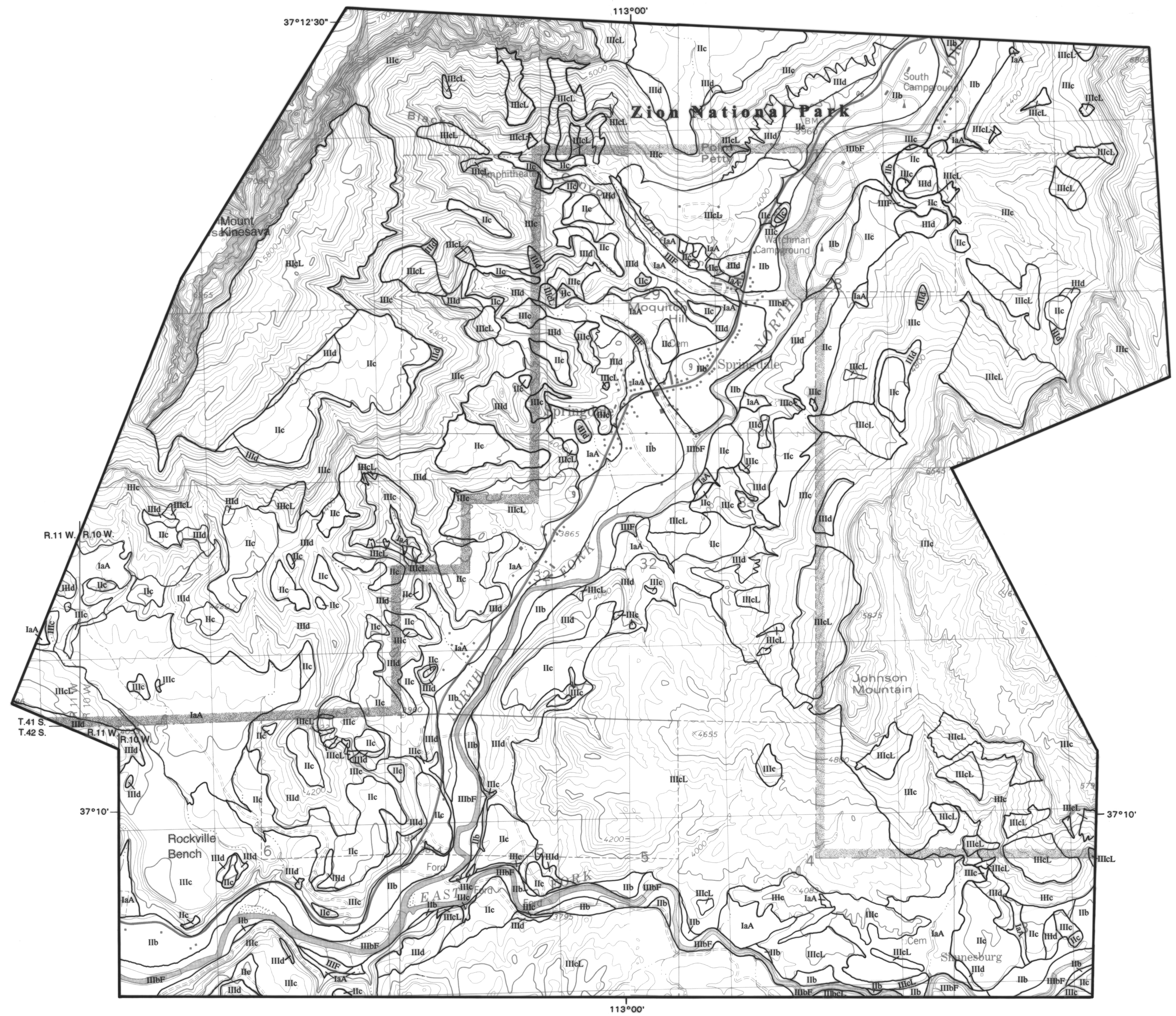
A Alluvial-fan flood and debris flow
F Stream flood (100-year flood plain)
L Landslide (unstable slopes, existing landslide deposits)

** Refer to plates 1 (Landslide Hazard) and 2 (Flood Hazards and Problem Soils) for discussion of these hazards and recommendations for hazard-evaluation studies.

Examples of suitability with qualifier(s):

IaA Generally suitable, but expect collapsible soil and alluvial-fan-flood and debris-flow hazards that may need to be accomodated with proper site design.
IIb Locally suitable conditions exist, but some areas are unsuitable due to shallow ground water.
IIIc Generally unsuitable due to shallow bedrock; other limiting conditions may apply but are not noted.

Base from Springdale West and Springdale East, Utah, USGS 7.5-minute topographic quadrangle maps.
Drafted by B.H. Mayes



SCALE 1:14,400

1 0.5 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 0.5 0 1 KILOMETER

CONTOUR INTERVALS 40 AND 80 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

MN 14 1/2° 258 MILS
UTM GRID AND 1980 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET
SPRINGDALE WEST QUADRANGLE

MAP LOCATION

Geologic Factors Affecting Relative STSA-System Suitability Categories

Suitability Category	Qualifiers[1]				Geologic Hazards		
	Collapsible Soil (a)	Shallow Ground Water (b)	Shallow Bedrock (c)	Steep Slope (d)	Alluvial-Fan Flood and Debris Flow (A)	Stream Flood (F)	Landslide (L)
I	Yes[2]				Yes		
II		Yes	Yes				
III		Yes	Yes	Yes		Yes	Yes

[1]Qualifiers are geologic conditions that limit site suitability and/or indicate the need for STSA-system design to minimize the impact of the conditions.

[2]"Yes" indicates that the geologic condition or hazard may impose limitations, but is not necessarily present everywhere; a blank indicates the geologic condition or hazard is either not present, or not a principal geologic factor affecting the suitability category.

DISCUSSION

Geologic studies were first conducted in southwestern Utah during military surveys to aid in military administration and operations and to establish railroad routes from the Missouri River to the Pacific Ocean. General John C. Fremont briefly passed through the region in 1844 and noted the unique vegetation, topography, and geology, but more extensive scientific investigation was not undertaken until 1871. In that expedition, Lt. George M. Wheeler described Parunuweap Canyon, south of Springdale:

> "The situation of Schoonesburg is exceedingly romantic. Mesa-locked as it is by the huge, steep escarpment of the semiplateau forms at either hand, it lies ensconced in a little opening, a sparkling gem, dropped as it were through the mountains upon the desert."

One of the principal geologists of the Wheeler Survey was the great American geomorphologist G.K. Gilbert, who first described Zion Canyon and the Springdale vicinity:

> "The North Fork [of the Virgin River] has opened a valley..., but too narrow for cultivation. From the foot of this valley to the hamlet of Little Zion the stream traverses, in the most wonderful defile it has been my fortune to behold, the massive sandstones of the Gray and Vermilion Cliffs, here combined in a single undistinguishable body, certainly not less than 2,000 feet in depth."

Although geologic studies continued in the Springdale region, most were concerned with the nature of ancient processes which formed the unique landscape. Few of the geologic studies described geologic hazards (geologic processes that present a risk to life and property) and those studies only dealt peripherally with such hazards. Yet, **geologic hazards are important factors to be considered prior to development, and developmental pressures are increasing** in Springdale as more people decide to live in the beautiful surroundings described by Wheeler, Gilbert, and so many others since. In slightly more than a century after the settlement of Springdale in 1863, its population reached 182 in 1970. However, the Springdale population grew by an additional 50 percent, to 275, by 1990 (the last year population estimates are available), and has continued to rapidly increase. Many hundreds of thousands of visitors to adjacent Zion National Park also pass through Springdale each year.

USE OF THIS MAP

This map shows the geology of Springdale. I first mapped the geology on aerial photographs in the summer and fall of 1994, and air-photo maps were then field checked in October and November, 1994. Four sets of air photos were used for mapping: (1) for the entire study area, U.S. Department of Agriculture black-and-white air photos, at a scale of 1:20,000, taken in 1960; (2) for the southern half of the study area, Intrasearch color air photos, 1:24,000, 1983; (3) for the North Fork Virgin River flood plain and adjacent foothills, WAC Corp. color air photos, 1:12,000, 1992; and (4) for a more detailed view of the North Fork Virgin River flood plain, WAC Corp. color air photos, 1:4,000, 1992.

Each map unit consists of a distinct assemblage of geologic materials distinguished by physical characteristics, geomorphic form, topographic position, and age. These distinguishing features are **commonly related to particular geologic hazards** and, thus, the distribution of geologic units controls the distribution of related geologic hazards. This geologic map was the primary source of information used to construct the accompanying hazard maps (plates 1 through 4), and may be consulted to obtain additional insight into geologic hazards in Springdale.

Relationships between map units and geologic hazards are summarized in the accompanying table. Three examples illustrate these relationships:

- Collapsible soil is in loose, dry, low-density deposits, which decrease in volume or collapse when saturated for the first time since deposition. These deposits result from rapid deposition and drying and are commonly associated with Holocene-age alluvial-fan sediments. Therefore, Holocene-age alluvial-fan sediments (unit Qaf) on plate 5A are shown as a collapsible-soil hazard on plate 2. This interpretation is substantiated by reported collapsible soil in an alluvial fan in northeast Springdale (Delta Geotechnical Consultants, Inc., 1995).

- Shallow ground water is in permeable deposits adjacent to bodies of surface water. Depending on the amount and nature of ground-water recharge, shallow ground water may discharge into the surface water and contribute to its volume, or surface water may infiltrate into the ground and provide an additional source of ground-water recharge. Permeable deposits adjacent to surface water in Springdale include alluvium along the Virgin River and its North and East Forks. Therefore, permeable alluvial deposits (units Qal_1, Qal_2, and Qat_1) on plate 5A are shown as areas of shallow ground water on plate 3. This interpretation is substantiated by shallow ground water in several wells drilled in the flood plain of central and southern Springdale (Utah Division of Water Rights, unpublished data).

- Radon is generated in rock or soil with high uranium concentrations, and travels easily through permeable, dry foundation materials. These conditions are common in the Chinle and Moenkopi Formations, where coarse-grained rock layers are uraniferous, well-drained, and permeable, and fine-grained rock is uraniferous, well-drained, and impermeable but overlain by permeable colluvium. Therefore, rocks in the Triassic Chinle (units Trcs and Trcp) and Moenkopi (unit Trmu) Formations, and overlying Quaternary colluvium (unit Qc) on plate 5A are shown as a high relative indoor-radon hazard on plate 3. This interpretation is supported by a detailed study of the indoor-radon-hazard potential of similar rocks in the St. George area, about 30 miles (50 km) southwest of Springdale (Solomon, 1995).

The **correlation of map units** on plate 5B shows the relationship between the ages of mapped geologic units, and the **description of map units** shows the characteristic features of each unit. The **stratigraphic column** on plate 5B summarizes local bedrock stratigraphy, tabulates thicknesses of bedrock units, graphically illustrates rock types (lithology), and presents a schematic erosional profile. The **geologic cross section** illustrates the geologic structure of nearly horizontal bedrock along the canyon walls and beneath the Virgin River, but lacks sufficient detail to accurately illustrate the geomorphic relationships of Quaternary unconsolidated deposits.

ACKNOWLEDGEMENTS

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Base from Springdale West and Springdale East, Utah, USGS 7.5-minute topographic quadrangle maps.
Drafted by B.H. Mayes

Relationship Between Geologic Map Units (Plates 5A and 5B) and Mapped Geologic Hazards (Plates 1 through 4).
Shading shows geologic units with the lowest relative-hazard potential for designated geologic hazards.
Follow guidelines on plates 1 through 4 for recommended requirements for site-specific investigations.

Plate Number	Hazard	Geologic Unit[1]																											
		Qa	Qac	Qaf	Qal_1	Qal_2	Qal_3	Qat_1	Qat_2	Qat_3	Qat_4	Qc	Qms_1	Qms_2	Qms_3	Qms_4	Qmt_1	Qmt_2	Qp	Jtw	Jts	Jn	Jk	Jms	Jmw	Jmd	Trcp	Trcs	Trmu
1	Landslide	Low[2]										Low-Mod	Moderate-High					Low					Low-Mod	Moderate		Low-Moderate		Low	Low-Mod
2	Stream flood	Out	In-Out		In		Out	In-Out	Out																				
	Alluvial-fan flood	In	Out	In	Out																								
	Debris flow	In	Out	In	Out																								
	Collapsible soil	In	Out	In	Out																								
	Expansive Soil	Low					Low-Mod	Low	Moderate				High	Moderate-High			Moderate		Low				Mod	Low	Mod		High	Low	Mod
	Gypsiferous soil	Out									In	In-Out					In		Out				In	Out					In
3	Liquefaction	Out			In		Out	In	Out																				
	Shallow ground water	Out			In		Out	In	Out																				
	Rock fall	Low	Mod	Low-High	Low		Mod-High	Low	Moderate			Low-High	Moderate-High				High										Mod	High	
	Indoor radon	High			Moderate		High	Mod	High		Low	Low-High					High	Low	High	Low							High		
4	Septic tank	I	II	I	III	II-III	II	II-III	II		II-III		III				II-III	III											

[1]Refer to the description of map units (plate 5B) for explanation of geologic unit symbols.

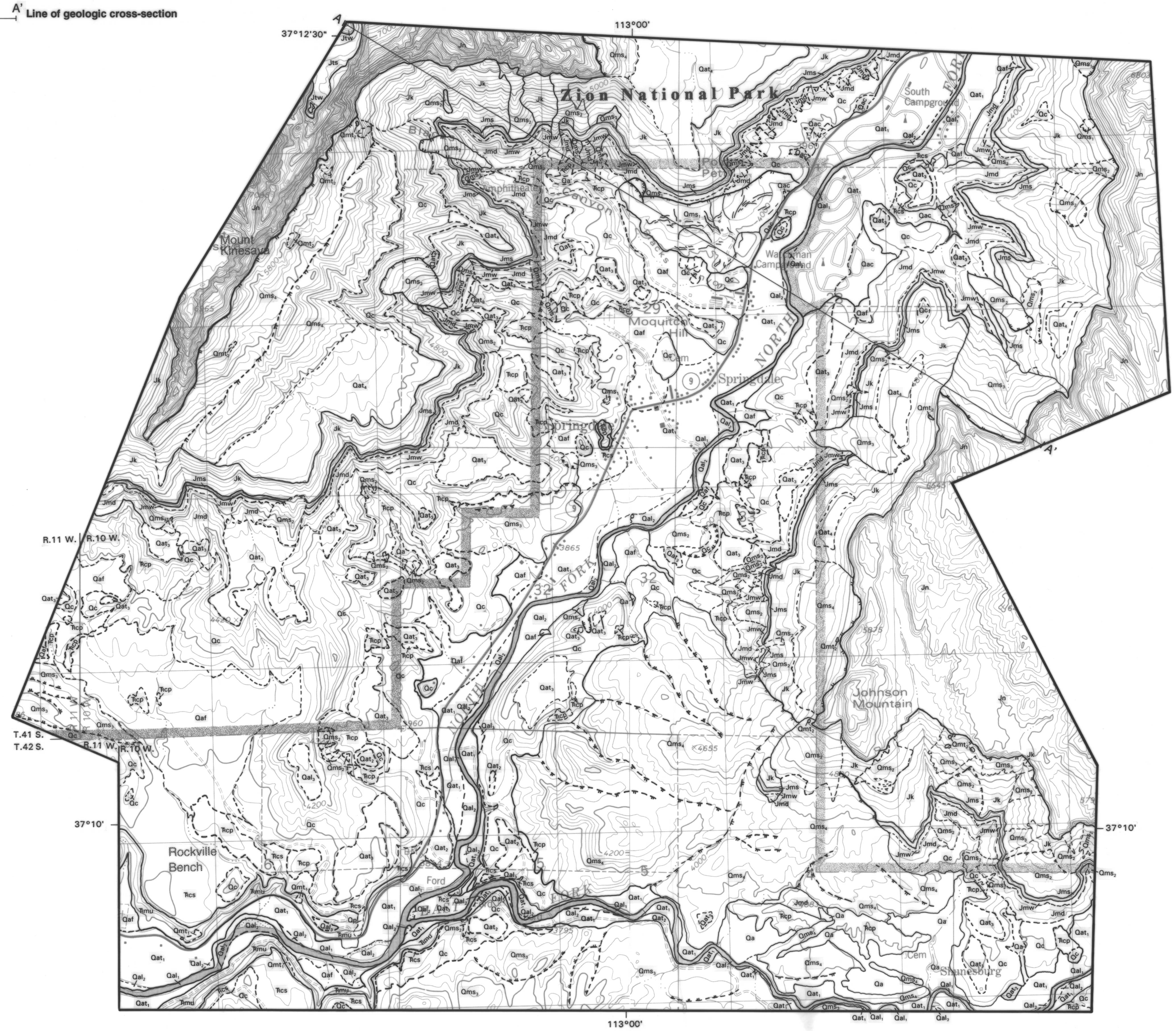
[2]Geologic units are either inside (In) or outside (Out) designated hazard areas, in designated relative-hazard zones (High, Moderate, or Low), or in designated septic-tank soil-absorption suitability categories (I, II, or III).

MAP SYMBOLS

- **Contact**--dashed where approximate
- **Landslide scarp**--hachures point in direction of movement, dashed where approximate
- **Fractures**--prominent fractures and fissures on the Springdale landslide.
- **Spring**
- A A' **Line of geologic cross-section**

Maps in this folio:

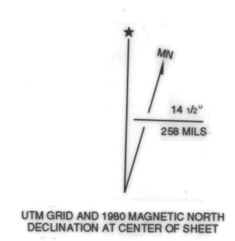
- Landslide Hazard (Plate 1)
- Flood Hazards and Problem Soils (Plate 2)
- Earthquake Hazards, Shallow Ground Water, Rock-Fall Hazard, and Indoor-Radon Hazard (Plat
- Suitability for Wastewater Disposal in Septic-Tank Soil-Absorption Systems (Plate 4)
- Geologic Map (Plate 5A)
- Description and Correlation of Map Units, Stratigraphic Column, and Geologic Cross Section (Pl



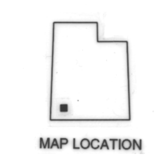
SCALE 1:14,400

1 0.5 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 0.5 0 1 KILOMETER

CONTOUR INTERVALS 40 AND 80 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929



UTM GRID AND 1980 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET
SPRINGDALE WEST QUADRANGLE



MAP LOCATION

PLATE 5A

GEOLOGIC MAP, SPRINGDALE, WASHINGTON COUNTY, UTAH

Barry J. Solomon
1996

Maps in this folio:
- Landslide Hazard (Plate 1)
- Flood Hazards and Problem Soils (Plate 2)
- Earthquake Hazards, Shallow Ground Water, Rock-Fall Hazard, and Indoor-Radon Hazard (Plate 3)
- Suitability for Wastewater Disposal in Septic-Tank Soil-Absorption Systems (Plate 4)
- Geologic Map (Plate 5A)
- Description and Correlation of Map Units, Stratigraphic Column, and Geologic Cross Section (Plate 5B)

DESCRIPTION OF MAP UNITS
(see plate 5A for references)

QUATERNARY UNCONSOLIDATED DEPOSITS

Alluvial Deposits

Qa **Undifferentiated alluvium (Holocene)**-- Fine- to coarse-grained alluvium on gentle slopes, primarily near ephemeral streams draining into the East Fork Virgin River. Includes low alluvial-terrace, alluvial-fan, alluvial-channel, and colluvial deposits that grade into each other and cannot be differentiated at the map scale. Mostly fine to medium sand, with pebbles, cobbles, and boulders, and lesser amounts of interbedded clay and silt. Generally reddish brown to pale brown, poorly to well stratified, and less than 20 feet (6 m) thick.

Qac **Undifferentiated alluvium and colluvium (Holocene)**--Alluvium with a significant colluvial component on moderate slopes near ephemeral streams draining into the North Fork Virgin River; includes stream-reworked colluvium. Poorly sorted clay, silt, sand, pebbles, cobbles, and boulders; coarser grained on steeper slopes. Generally reddish brown to pale brown, poorly stratified, and less than 10 feet (3 m) thick.

Qaf **Alluvial-fan deposits (Holocene)**--Coarse- to fine-grained alluvial-fan and debris-flow sediments deposited in individual alluvial fans at canyon mouths along the North Fork Virgin River and in coalesced alluvial fans on the Rockville Bench southwest of Springdale. Reddish brown to pale brown, poorly sorted clay, silt, sand, pebbles, cobbles, and boulders on sloping, fan-like surfaces, with finer deposits downslope. Alluvial-fan deposits are thickest near the fan apices and thin to a feather edge toward the valley, but are generally less than 20 feet (6 m) thick.

Qal_1 **Stream alluvium in active channels (Holocene)**--Sand, silt, and clay beds with thin gravel layers and lenses, in the active channels of the Virgin River and its North and East Forks. Generally reddish brown to pale brown, with well-stratified fine to medium sand. Probably less than 30 feet (9 m) thick. Equivalent to the active channel and flood-plain deposit of Hereford and others (1995).

Qal_2 **Flood-plain alluvium (Holocene)**--Sand, silt, and clay beds with thin gravel layers and lenses, in flood plains, abandoned stream meanders, and associated point bars of the Virgin River and its North and East Forks. Generally reddish brown to pale brown, with well-stratified fine to medium sand. Probably less than 30 feet (9 m) thick. Equivalent to the modern terrace deposits of Hereford and others (1995).

Qal_3 **Older alluvium (Pleistocene)**--Coarse sand and granule- to boulder-size gravel, pale yellow to light brown, in three isolated outcrops near the confluence of the North and East Forks of the Virgin River. The gravel is well-rounded and composed mainly of sandstone and limestone clasts, with minor amounts of basaltic clasts. The alluvium once filled ancient channels in local canyons, and probably includes alluvial-fan as well as channel deposits, but the canyons have substantially widened and deepened since deposition and only isolated remnants of the deposit remain. Dalness (1969) informally named this unit the Orderville gravel and assigned it a Holocene age, but Hereford and others (1995) reassigned it to the Pleistocene based on stratigraphic position beneath Holocene alluvial-terrace deposits and above the Pleistocene Parunuweap Formation. South of Orderville the unit is as much as 60 feet (20 m) thick (Dalness, 1969), but is less than 15 feet (5 m) thick near Springdale.

Qat_1 **Alluvial-terrace deposits, unit 1 (Holocene)**--Sand, silt, and clay beds with thin gravel layers and lenses, overlies terraces slightly above the adjacent Virgin River and its North and East Forks. The terraces are from 5 to 15 feet (2-5 m) above the modern flood plain. Deposits are generally reddish brown to pale brown, with well-stratified fine to medium sand, and are as much as 10 feet (3 m) thick. Hereford and others (1995) subdivided equivalent terraces nearby into three units of latest Holocene age, based on archeologic evidence, tree-ring chronology, historic documents, and correlation with other streams on the southern Colorado Plateau: prehistoric, settlement, and historic terraces.

Qat_2 **Alluvial-terrace deposits, unit 2 (Pleistocene)**--Sand and gravel, reddish brown, on terrace remnants about 100 to 150 feet (30-45 m) above the North and East Forks of the Virgin River. The most extensive remnants are on the lower part of the Petrified Forest Member of the Chinle Formation in the foothills near the confluence of the North and East Forks. Gravel is mostly pebble-sized and subrounded, but cobbles and boulders as much as 1.5 feet (0.5 m) in diameter are found. Estimated maximum thickness of deposits is 15 feet (5 m). This unit is equivalent to the low terrace of Coney (1959) and Eardley (1965). In the vicinity of Rockville, west of Springdale, the low terrace is cut into rocks of the Pleistocene Parunuweap Formation, and is thus younger than that unit. Eardley (1965) postulates a Pleistocene age for the low terrace based on rates of Quaternary uplift and erosion for the Colorado Plateau.

Qat_3 **Alluvial-terrace deposits, unit 3 (Pleistocene)**--Sand and gravel, reddish brown, on terrace remnants about 250 to 450 feet (75-140 m) above the Virgin River and its North and East Forks. The most extensive remnant is on the eastern slope of Mt. Kinesava beneath the ledge formed by the Springdale Sandstone Member of the Moenave Formation. Gravel is mostly pebble sized and subrounded, but cobbles and boulders as much as 1.5 feet (0.5 m) in diameter are found. Estimated maximum thickness of deposits is 20 feet (6 m). This unit is equivalent to the intermediate terrace of Coney (1959) and Eardley (1965). The intermediate terrace is at higher elevations than the low terrace, and is thus older. Eardley (1965) postulates a Pleistocene age for the intermediate terrace based on rates of Quaternary uplift and erosion for the Colorado Plateau.

Qat_4 **Alluvial-terrace deposits, unit 4 (Pleistocene)**--Sand and gravel, reddish brown, on terrace remnants about 1,000 to 1,300 feet (300-400 m) above the North Fork of the Virgin River. The most extensive remnants are on the eastern slope of Mt. Kinesava and north of Point Petty, above the ledge formed by the Springdale Sandstone Member of the Moenave Formation. Gravel is mostly pebble sized and subrounded, but cobbles and boulders as much as 1.5 feet (0.5 m) in diameter are found. Estimated maximum thickness of deposits is 25 feet (8 m). This unit is equivalent to the high terrace of Coney (1959) and Eardley (1965). The high terrace is at higher elevations than the intermediate terrace, and is thus older. Eardley (1965) postulates a Pleistocene age for the high terrace based on rates of Quaternary uplift and erosion for the Colorado Plateau.

Colluvial Deposits

Qc **Colluvium (Pleistocene and Holocene)**--Loose clay, silt, sand, pebbles, cobbles, and boulders covering bedrock units on valley slopes. Generally reddish brown and up to 20 feet (6 m) thick. Colluvium is most common on slopes underlain by the Petrified Forest Member of the Chinle Formation. Debris is coarser grained upslope, reflecting the greater relative contribution upslope of sandstone debris from coarse-grained beds overlying the Petrified Forest Member, and downslope of mud from fine-grained beds within the Petrified Forest Member. Colluvium is primarily derived from disintegration of overlying bedrock by erosion and downslope creep, but may be locally derived from landslides and rock falls which have left no recognizable geomorphic evidence.

Mass-Movement Deposits

Qms_1 **Active landslide deposits (Holocene)**--Slumps consisting of landslide blocks of bedrock with distorted bedding and steep dips, and slides consisting of chaotic mixtures of matrix-supported clasts. Active landslides are characterized by sharp, unvegetated scarps, and have probably moved within the last 100 years. Deposits include complex block slides on the north edge of Blacks Canyon and along Paradise Road that resulted from the 1992 St. George earthquake, a small slump south of Moquitch Hill that occurred in 1989, and two debris slides east of the South Campground in Zion National Park whose precise age is unknown. The complex block slides and slump resulted from failure of the Petrified Forest Member of the Chinle Formation, whereas the debris slides resulted from failure of the Kayenta Formation. The landslide north of Blacks Canyon has an average thickness of 115 feet (35 m)(Jibson and Harp, 1995), but thicknesses of other active landslides are less.

Qms_2 **Young inactive landslide deposits (Holocene)**--Slumps consisting of landslide blocks of bedrock with distorted bedding and steep dips, and slides consisting of chaotic mixtures of matrix-supported clasts. Young inactive landslides are characterized by sharp, partly vegetated scarps, and have probably moved between 100 and 5,000 years ago. Deposits include the complex block slide south of the Springdale central business district and east of the Virgin River North Fork, and several debris slides on the canyon slopes. The complex block slide resulted from failure of the Petrified Forest Member of the Chinle Formation, whereas the debris slides resulted from failure of the Kayenta Formation, Dinosaur Canyon and Whitmore Point Members of the Moenave Formation, and colluvium overlying the Petrified Forest Member. The complex block slide has a maximum thickness of about 100 feet (30 m), but thicknesses of other young inactive landslides are less.

Qms_3 **Mature inactive landslide deposits (Pleistocene and Holocene)**--Slumps consisting of landslide blocks of bedrock with distorted bedding and steep dips, and slides consisting of chaotic mixtures of matrix-supported clasts. Mature inactive landslides are characterized by smooth, vegetated scarps and smoother topography than younger landslide deposits. Most probably moved between 5,000 and 10,000 years ago, although movement of the Eagle Crags landslide south of the Virgin River East Fork, and extending beyond the map boundary, probably began in the Pleistocene and extended into the early Holocene (Shroder, 1971). In addition to the Eagle Crags landslide, deposits include the complex block slide southwest of the Springdale central business district and west of the Virgin River North Fork, two smaller slumps nearby, a complex block slide above the Rockville Bench, and four debris slides on canyon slopes south and east of Springdale. The complex block slides and slumps resulted from failure of the Petrified Forest Member of the Chinle Formation, whereas the debris slides resulted from failure of the Kayenta Formation. The Eagle Crags landslide has an average thickness of 50 feet (15 m), but thicknesses of other mature inactive landslides are less.

Qms_4 **Old inactive landslide deposits (Pleistocene)**--Slumps consisting of landslide blocks of bedrock with distorted bedding and steep dips. Old inactive landslides are characterized by dissected and vegetated scarps, smoother topography than younger landslide deposits, and internal drainage that is integrated with the drainage system beyond the landslide boundary. Old inactive landslides probably moved more than 10,000 years ago. Deposits include the Johnson Mountain landslide, a complex block slide southeast of Springdale, and two similar landslides truncated by high alluvial-terrace remnants (alluvial-terrace deposits, unit 4) near Mt. Kinesava and Point Petty. The Johnson Mountain landslide resulted from failure of the Petrified Forest Member of the Chinle Formation, but the other old landslides resulted from earlier failure of the Kayenta Formation when the Virgin River was at a higher elevation. The Johnson Mountain landslide has an average thickness of 50 feet (15 m), and the other old inactive landslides are about 150 feet (45 m) thick.

Qmt_1 **Young talus deposits (Holocene)**--Clast-supported sand and coarse, angular sandstone rock fragments to 3 feet (1 m) in diameter, yellowish brown and pale brown, in lobes beneath cliffs of the Shinarump Member of the Chinle Formation. Maximum thickness 20 feet (6 m).

Qmt_2 **Old talus deposits (Pleistocene and Holocene)**--Massive blocks of sandstone, light brown to orange brown, at the base of Navajo Sandstone cliffs. The largest block, on the east flank of Mt. Kinesava, is about 300 feet (90 m) long. This and other blocks may be related to the underlying Pleistocene landslide deposit, cliff recession, and valley widening, but may also be the result of later, local rock-fall events.

CENOZOIC SEDIMENTARY ROCKS

Qp **Parunuweap Formation (Pleistocene)**--Conglomerate, reddish brown, consisting of pebbles, cobbles, boulders, and angular blocks in a fine- to medium-grained sandy matrix cemented with calcium carbonate and minor amounts of iron oxide. Pebbles, cobbles, and boulders up to 1 foot (0.3 m) in diameter are commonly basalt and andesite derived from the Kolob volcanic field, but also include lesser amounts of sandstone, limestone, shale, quartzite, and chert. Large angular blocks of sandstone derived from local outcrops of the Shinarump Member of the Chinle Formation are up to 4 feet (1.2 m) in diameter. Bedding is very crude and massive. Only one outcrop of the Parunuweap Formation is mapped near Springdale, near the confluence of the North and East Forks of the Virgin River, where a maximum thickness of 15 feet (5 m) is exposed. Elsewhere in the Virgin River Valley, the Parunuweap Formation has a maximum thickness of 75 feet (23 m)(Dalness, 1969). The Parunuweap Formation was informally named by Gregory (1945) for outcrops in Long Valley, about 23 miles (37 km) northeast of Springdale, and Dalness (1969) designated and described the type locality there. The Parunuweap Formation was apparently deposited by fluvial channels and debris flows during a period of intense sedimentation in high-energy environments. Dalness (1969) attributed deposition of the Parunuweap Formation to either (1) uplift of the Kolob Terrace by the Hurricane fault and associated aggradation in the upper Virgin River drainage basin, or (2) increased runoff and contributions of detritus from melting ice masses near the end of a glacial stage. The age of the Parunuweap Formation is restricted to a limited part of the Pleistocene between creation of the intermediate terrace (alluvial-terrace deposits, unit 3), which is at higher elevations than the Parunuweap and thus older, and the lower terrace (alluvial-terrace deposits, unit 2), which has been cut into some Parunuweap outcrops in the Virgin River Valley and is thus younger.

MESOZOIC SEDIMENTARY ROCKS

Jurassic System

Temple Cap Sandstone (Middle Jurassic)--The Temple Cap Sandstone, formerly a member of the Navajo Sandstone, was raised to formation rank and subdivided into two members by Peterson and Pipiringos (1979). The two members of the Temple Cap Formation are, in descending order, the White Throne and Sinawava Members. The total thickness of the formation in the map area at The West Temple is 280 feet (90 m).

Jtw **White Throne Member**--Sandstone, fine to medium grained, gray to pink, high-angle cross-bedding, massive and cliff-forming, maximum thickness 160 feet (50 m). The White Throne Member is the product of desert dune deposition.

Jts **Sinawava Member**--Mudstone, silty shale, and fine- to medium-grained sandstone, reddish orange to reddish brown, slope-forming, with a locally conglomeratic basal sandstone bed. Contact with the overlying White Throne Member is conformable and probably intertonguing. Thickness 120 feet (40 m). The Sinawava Member was deposited in an arid, flood-plain environment.

Jn **Navajo Sandstone (Lower Jurassic)**--Sandstone, fine to medium grained, with minor siltstone and mudstone; pale orange, reddish orange, reddish brown, pale to moderate red, and gray; large-scale cross-beds; forms steep cliffs. The upper contact with the overlying Sinawava Member of the Temple Cap Formation is sharp and nearly planar, corresponding to the J-1 unconformity of Pipiringos and O'Sullivan (1978). Maximum thickness about 2,150 feet (650 m). The Navajo Sandstone, a cross-bedded sandstone that extends from north-central Wyoming to Nevada and Arizona, is of probable eolian (windblown) origin. The unit was first named by Gregory (1916).

Jk **Kayenta Formation (Lower Jurassic)**--Gypsiferous siltstone, mudstone, sandstone, and shale; reddish orange to pale red; sandstone is very fine grained and silty, and exhibits small-scale cross-beds; mudstones form earthy slopes. The upper contact is gradational with the overlying Navajo Sandstone. Maximum thickness about 600 feet (180 m). Kayenta strata are accumulations of sediment deposited by a large system of streams flowing westward from the ancestral Rocky Mountains. The Kayenta Formation was first named by Baker (1933).

Moenave Formation (Lower Jurassic)--The Moenave Formation was previously included in the upper part of the Chinle Formation by Gregory (1950), but the Moenave was later described in northern Arizona as a distinct formation by Harshbarger and others (1957). In the Springdale area, three members of the Moenave Formation are recognized. In descending order, these members are the Springdale Sandstone, Whitmore Point, and Dinosaur Canyon Members. The total thickness of the formation in the Springdale area is about 375 feet (114 m).

Jms **Springdale Sandstone Member**--Sandstone, very fine grained, minor sandy mudstone and conglomerate; pale red to light brown, weathers grayish orange and grayish orange pink; horizontal beds interbedded with large-scale cross-beds; forms persistent cliff. The upper contact is gradational with the overlying Kayenta Formation. Maximum thickness about 105 feet (32 m). The unit was probably deposited by energetic streams flowing from source areas in the ancestral Rocky Mountains toward the west and southwest across a broad alluvial plain.

Jmw **Whitmore Point Member**--Sandstone, very fine grained, siltstone, and minor mudstone; gray and pinkish gray; planar beds, wavy laminations, and cross-laminae; forms an earthy slope. The upper contact is gradational with the overlying Springdale Sandstone. Maximum thickness about 65 feet (20 m). The Whitmore Point Member was deposited in a fresh-water, well-oxygenated lake.

Jmd **Dinosaur Canyon Member**--Siltstone, mudstone, and silty, very fine-grained sandstone; reddish brown to reddish orange; planar laminae and small-scale cross-laminae; forms alternating sandstone and siltstone ledges and mudstone slopes. The upper contact is gradational with the overlying Whitmore Point Member. Maximum thickness about 205 feet (62 m). Deposited by streams flowing northward from the Mogollan Highlands in northern Arizona.

Triassic System

Chinle Formation (Upper Triassic)--Gregory (1916) originally defined the Chinle Formation as thick variegated shale overlying the Shinarump Conglomerate in Chinle Valley, northeast Arizona. Gregory and Williams (1947) redefined the variegated shale as the Petrified Forest Member, and the basal conglomerate as the Shinarump Member, of the Chinle Formation. Total thickness of the Chinle Formation in the Springdale area is about 510 feet (157 m).

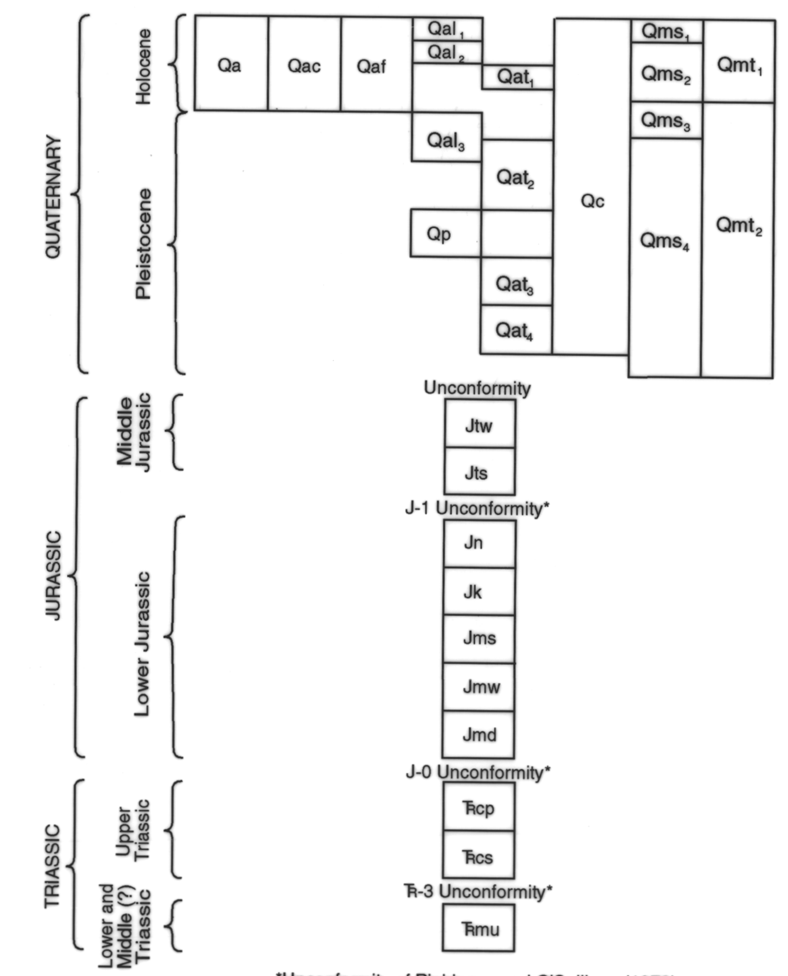
Ƭcp **Petrified Forest Member**--Variegated silty claystone, subordinate very fine-grained sandstone and volcanic ash altered to bentonitic clay; light gray, pale red, pale red purple, pale olive, light greenish gray, and light bluish gray; horizontal, planar beds; soft, erosive claystone weathers to a "popcorn" surface that reflects the expansive clay-mineral content. The upper contact is the extensive J-O unconformity at the base of the Glen Canyon Group (see stratigraphic column) that bevels successively older parts of the Chinle Formation from southeast to southwest Utah (Pipiringos and O'Sullivan, 1978), although the upper contact near Springdale is usually covered by colluvium from the overlying Dinosaur Canyon Member of the Moenave Formation. Maximum thickness of the Petrified Forest Member near Springdale is about 390 feet (120 m). The unit was deposited in flood plains and lakes under a moist climate.

Ƭcs **Shinarump Member**--Sandstone, medium to coarse grained and pebbly, and sandy conglomerate; well-rounded clasts of quartz, quartzite, and chert; gray to pale grayish orange; large-scale cross-beds, horizontally planar beds, and massive, structureless beds; forms resistant caprock and gently sloping bench (the Rockville Bench) that extends west from the southwest corner of the study area, and forms resistant ledge near the confluence of the North and East Forks of the Virgin River. The contact between the Shinarump and Petrified Forest Members is gradational. Maximum thickness of the Shinarump Member near Springdale is about 120 feet (37 m). The unit was deposited during a period of fluvial aggradation and lateral accretion of gravel and sand in channels and on point bars of streams.

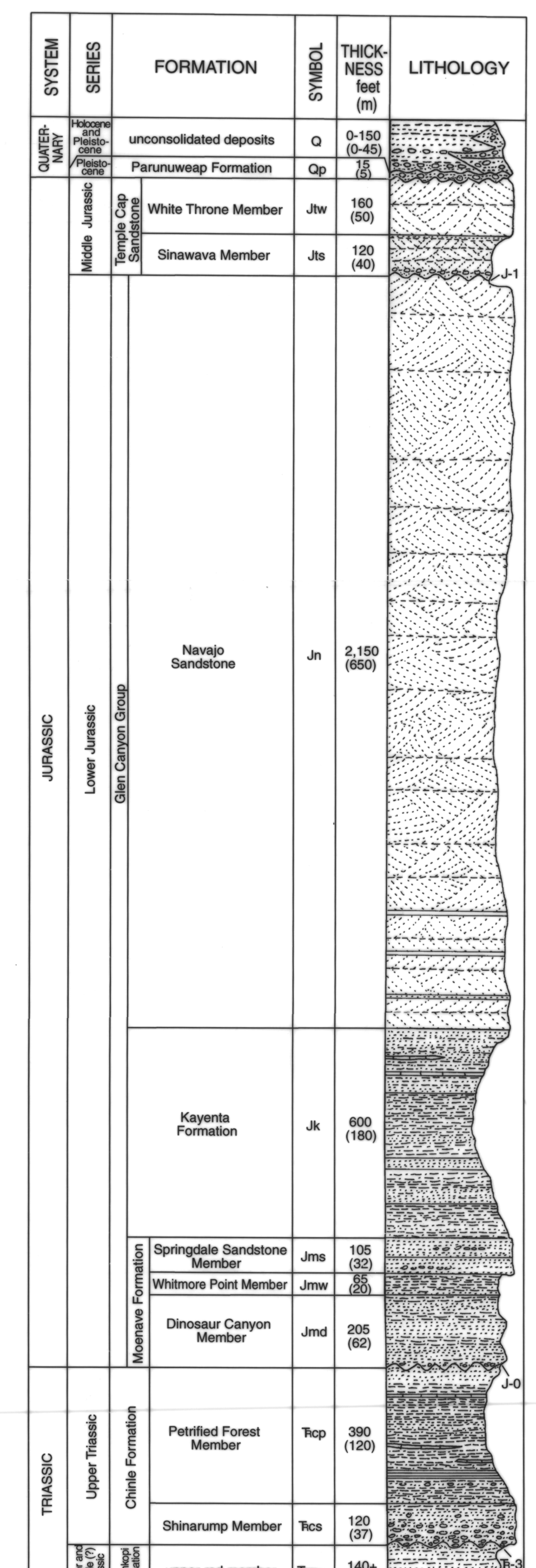
Ƭmu **Moenkopi Formation, upper red member (Lower and Middle(?) Triassic)**--Gypsiferous siltstone, very fine-grained sandstone, clayey siltstone, and silty mudstone; pale red and light brown; thin-bedded to laminated, commonly ripple-marked; forms earthy slopes. The top of the upper red member is beveled by a major regional unconformity, designated the Ƭ-3 unconformity by Pipiringos and O'Sullivan (1978). Only the upper part of the upper red member is exposed near Springdale, where the maximum exposed thickness is about 140 feet (43 m). The unit was deposited by west-flowing streams on a fluvial plain that prograded westward as the marine shoreline withdrew. The Moenkopi Formation was named by Ward (1901) for rocks exposed at Moenkopi Wash, Grand Canyon, Arizona.

Base from Springdale West and Springdale East, Utah, USGS 7.5-minute topographic quadrangle maps.
Drafted by B.H. Mayes

CORRELATION OF MAP UNITS



*Unconformity of Pipiringos and O'Sullivan (1978)



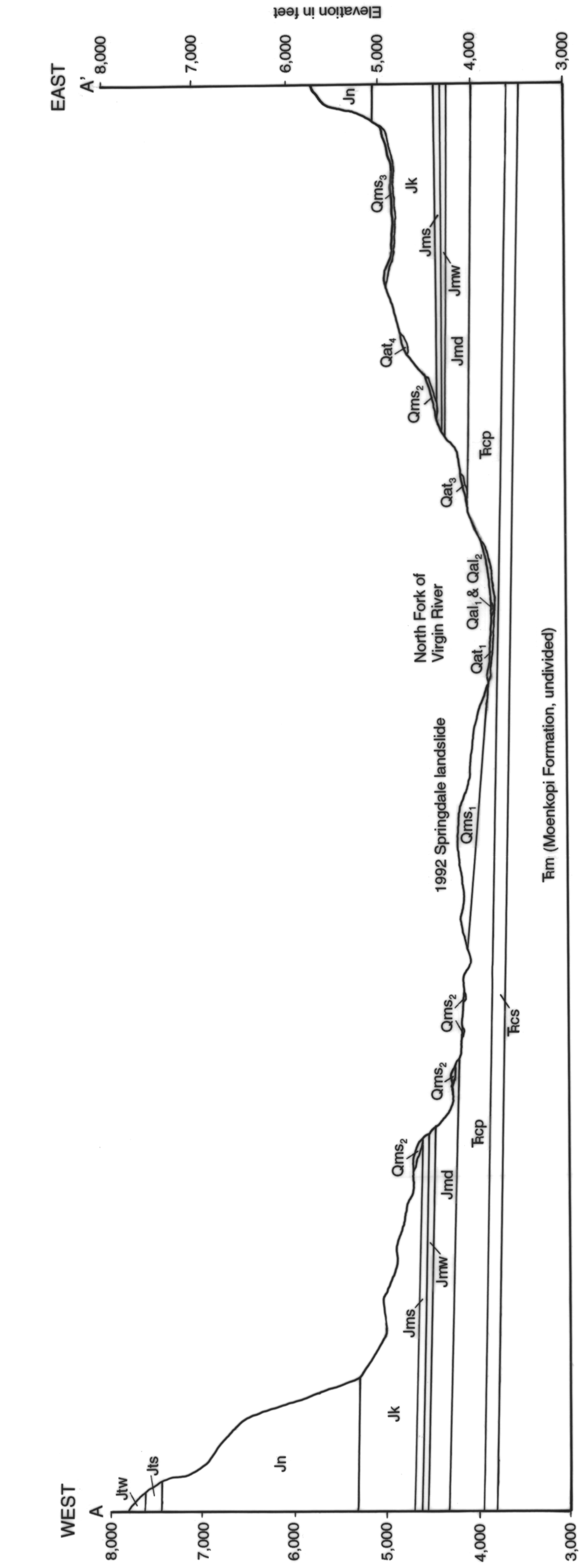


PLATE 5B

DESCRIPTION AND CORRELATION OF MAP UNITS, STRATIGRAPHIC COLUMN, AND GEOLOGIC CROSS SECTION, SPRINGDALE, WASHINGTON COUNTY, UTAH

Barry J. Solomon
1996