GEOLOGICAL HAZARDS: RISKS AND MITIGATION

8.1 Identifying and Profiling Geological Hazards

Geologic hazards are those geologic conditions that present a risk to life (injury or death), of substantial loss or damage to property, or damage to the environment. Geologic hazards affect Utah, negatively impacting life safety, health, property, and the state's economy. For the purpose of this mitigation plan, the term geological hazard is used to describe earthquakes, faults, fissures, ground cracks and liquefaction; volcanoes, stratovolcanoes, shield volcanoes and cinder cones; soil problems; landslides and rock falls and radon.

Major geological events in the past five years include a fatal rock fall in Rockville Washington County on December 12, 2013, the Parkway Drive Landslide in North Salt Lake Davis County on August 5, 2014, and in 2017 flooding and landslides in Box Elder County and the Spring Creek Road landslide in Riverdale.

While many geologic hazards are not life threatening, they are often costly when not recognized and properly accommodated in land-use management and project planning and design, and result in additional, significant construction and/or future maintenance costs, economic losses and injury or death.

Geologic hazards that are not accounted for in project planning and design often result in additional unforeseen construction and/or future maintenance costs, and possible injury or death. There is only limited information on the direct and indirect economic costs of geologic hazards in the United States, including Utah; however, some information is available for large landslide events. Landslides in the United States caused between $1.7 and $3.4 billion in damages each year.[1]

Since 1847, at least 6,067 deaths, as well as a significantly larger, but undetermined number of injuries and an undetermined financial cost have been attributed to geologic hazards in Utah. Radon gas exposure causing lung cancer has been Utah's most deadly geologic hazard, with over 5,630 fatalities (data only available from 1973 to 2015), followed by landslide hazards with 337 documented fatalities and flooding hazards accounting for 101 documented fatalities. As debris flows are both a landslide and flooding hazard, fatalities are listed in both hazard categories. Using the economic value of a statistical life of $11.6 million the 6,067 fatalities are valued at $67.2 trillion. For a 72-year old diagnosed with lung cancer in 2000, the cost of the first six months of care ranged from $16,122 (no active

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[1] Committee on Ground Failure Hazards, 1985

treatment) to $56,160 (chemo-radiotherapy) and varied by stage at diagnosis and histologic type.[2]

Table 1. Summary of known geologic-hazard fatalities in Utah

Geologic Hazard		Fatalities			
Landslide Hazards					
Landslides[1]		4	1.2%	337	5.6%
Rock fall		15	4.5%		
Debris Flows[2]		15	4.5%		
Snow Avalanches[3]		303	89.8%		
Earthquake Hazards					
Ground Shaking		2	100%	2	<0.1%
Flooding Hazards					
Flooding		81	80.1%	101	1.7%
Debris Flows[2]		15	14.9%		
Dam and Water Conveyance Structure Failure[1]		5	5.0%		
Problem Soils					
Radon Gas[4]	1973-2015	5630	100%	5630	92.7%
Total:		**6067**			

[1] Because of uncertainty in event initiation, three fatalities are listed in both the "Landslides" and "Dam and Water Conveyance Structure Failure" categories.
[2] Debris flows are both a landslide and flooding hazard.
[3] The majority of post-1950 snow avalanche fatalities are in the backcountry from human-induced avalanches; however, many have occurred near or in developed areas where appropriate mitigation measures should be used.
[4] Limited data are available and contain various assumptions; exact number of fatalities is unknown.

Damages as the result of many geologic hazards are often not covered by property or other insurance. There are exceptions and each policy should be reviewed for what damages are covered or excluded.

Homeowners property policies generally cover all-risks or perils (property losses and damages), except for those specifically excluded. Common exclusions are damages from earth movements, earthquakes, mudflows, mine subsidence, sinkholes, flooding, and environmental factors. Special policies may be available to cover specific named perils. Homeowners may be able to get coverage for generally excluded losses by adding them to an existing policy by endorsement or by the purchase of a separate policy. A difference in conditions policy provides coverage for some otherwise excluded perils and is also known as a catastrophe policy.

Multiple types of commercial property policies are available, however, earth movements such as earthquakes, mudflows, mine subsidence, sinkholes and flooding are commonly

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[2] Cipriano and others, 2011

excluded. Endorsements can typically be added to a policy to provide coverage for these perils and for expanding coverage for other perils.

Commercial auto policies have more options available and coverage must be specified for each vehicle or type of vehicle. Damages from geologic hazards may or may not be covered, depending on the policy. Personal auto policies generally cover all-risks or perils, including geologic hazards, such as earthquakes, flooding, falling objects, volcanic eruptions, etc. for individuals with collision and comprehensive coverage.

In almost all cases, it is more cost-effective to investigate and characterize potential hazards by performing a comprehensive engineering-geology investigation to identify and characterize geologic hazards and implement appropriate mitigation, rather than relying on additional maintenance over the life of a project and/or incurring costly construction change orders and other financial costs. UGS experts advocate living and dealing with geologic hazards by understanding what they are, where they exist, how large or difficult they are and how to effectively mitigate them.

To ensure that future development within Utah is protected from geologic hazards, the UGS recommends that a comprehensive engineering-geology and geotechnical engineering investigation be performed by licensed professionals for all development. Such investigations provide valuable information on site geologic conditions that may affect or be affected by development, as well as the type and severity of geologic hazards at a site and recommend solutions to mitigate the effects and the costs of the hazards, both at the time of construction and over the life of the development. Engineering-geology investigations and accompanying geologic-hazard evaluations may be performed independently or be included as part of a more broadly-based geotechnical investigation before project engineering design.

Much of this chapter has been derived from the Utah Geological Survey (UGS) Circular 122: *Guidelines for Investigating Geologic Hazards and Preparing Engineering-Geology Reports with a Suggested Approach to Geologic-Hazard Ordinances in Utah* publication available at https://ugspub.nr.utah.gov/publications/circular/c-122.pdf. As the UGS revises or develops new geologic-hazard guidelines, Circular 122 will be updated as appropriate. Refer to the URL link above for the most geologic hazard investigation and report guidelines and related information.

Geologic Hazards

Geologic hazards are defined in Utah Code as a “geologic condition that presents a risk to life, of substantial loss of real property, or of substantial damage to real property” (Title 17, Chapter 27a, Section 103.[3] Geologic hazards commonly encountered in Utah include, but are not limited to:

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[3] https://le.utah.gov/xcode/Title17/Chapter27A/17-27a-S103.html?v=C17-27a-S103_2015051220150512

- Earthquake (Seismic) Hazards, including
    - Earthquake ground shaking
    - Surface fault rupture (faults)
    - Liquefaction
    - Seiche
    - Tsunami
    - Tectonic deformation
    - Earthquake-triggered landslides and rock fall

- Landslide Hazards, including
    - Landslides
    - Rock fall
    - Debris flows
    - Snow avalanches (covered in the Other Hazards section of the state plan)

- Flooding Hazards, including
    - River, lake, or sheet flooding (covered in the Flooding Hazards section of the state plan)
    - Debris flows
    - Dam and water conveyance structure failure (covered in the Flooding Hazards section of the state plan)
    - Seiches
    - Tsunamis
    - Shallow Groundwater

- Problem Soil and Rock Hazards, including
    - Breccia pipes and karst
    - Caliche
    - Collapsible soils
    - Corrosive soil and rock
    - Expansive soil and rock
    - Gypsiferous soil and rock
    - Land subsidence and earth fissures
    - Piping and erosion
    - Radon gas
    - Salt tectonics
    - Shallow bedrock
    - Wind-blown sand

- Volcanic Hazards, including
    - Volcanic eruption
    - Lava flows
    - Airborne volcanic ash

Earthquake (Seismic) Hazards

Earthquakes also known as quakes, tremors or temblors are the sudden and violent shaking of the ground, resulting from movements within the earth's crust or volcanic action and the sudden release of energy in the Earth's lithosphere that creates seismic waves sometimes causing great destruction.

An earthquake occurs when two blocks of the earth suddenly slip past one another, releasing built up energy from plate tectonics, regional stress regimes, and/or induced from fluid injection or underground mining activities. The surface between these two blocks is called a fault or fault plane. When these blocks move, they produce seismic waves that are transmitted outward through the rock in all directions, producing ground shaking and secondary effects. Earthquakes are unique multi-hazard events with the potential to cause very large damages and loss of life. Earthquake secondary effects often include surface fault rupture (generally ≥ magnitude [M] 6.5), liquefaction and lateral spreading can be triggered as low as approximately 0.1 g.[4] Landslides, rock fall (generally ≥ M 4), tectonic subsidence, seiches and tsunamis. Effects from ground shaking may include building and infrastructure damage, fires, building and/or dam and canal failure, hazardous material releases, and non-structural building damage such as toppled cabinets, bookcases, and other furniture or equipment that was not restrained, falling ceiling tiles, lights, and other ceiling mounted items, and movement of unrestrained furniture, equipment and other building interior items.

Utah has experienced sixteen earthquakes greater than M 5.5 since pioneer settlement in 1847 (figure x, red stars) and geologic investigations of Utah's faults indicate a long geologic history of repeated large earthquakes of M 6.5 and greater prior to settlement. Utah is not on a boundary between tectonic plates where most of the world's earthquakes occur, but rather is in the western part of the North America plate. However, earthquakes in Utah are indirectly caused by interactions with the Pacific plate along the plate margin on the west coast of the United States. Also, many small earthquakes in east-central Utah are induced by underground coal mining.

Utah straddles the physiographic region boundary between the extending Basin and Range Province to the West and the relatively stable Rocky Mountains and the Colorado Plateau to the East. This boundary coincides with an area of earthquake activity called the Intermountain Seismic Belt (ISB). The ISB is a zone of significant earthquake activity up to 120 miles wide extending in north-south direction 800 miles from Canada to northern Arizona and eastern Nevada. Large, damage causing earthquakes in Utah are likely to occur in the ISB that generally extends though the center of the state, essentially following Interstate 15, where there are many active faults capable of producing earthquakes. Unfortunately, this location is also where over 85% of Utah's population lives along the Wasatch Front, and also includes the rapidly urbanizing St. George and Cedar City areas.

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[4] Keefer, 1984

Moderate to large earthquakes generally M 6 and greater cause substantial damage to buildings, roads, bridges and utilities often leading to injuries and fatalities. Background earthquakes are defined as those events less than M 6.75 ± 0.25 that cannot be associated with a known fault. A classic example of a background earthquake within the Wasatch Front region is the 1975 M 6.0 Pocatello Valley, Idaho, earthquake. Utah's only historical surface fault rupturing earthquake is the 1934 M 6.6 Hansel Valley earthquake that also caused two fatalities. Maps 1 and 2 show earthquakes known to have occurred within and surrounding Utah and also mapped Quaternary faults considered to be earthquake sources.[5]

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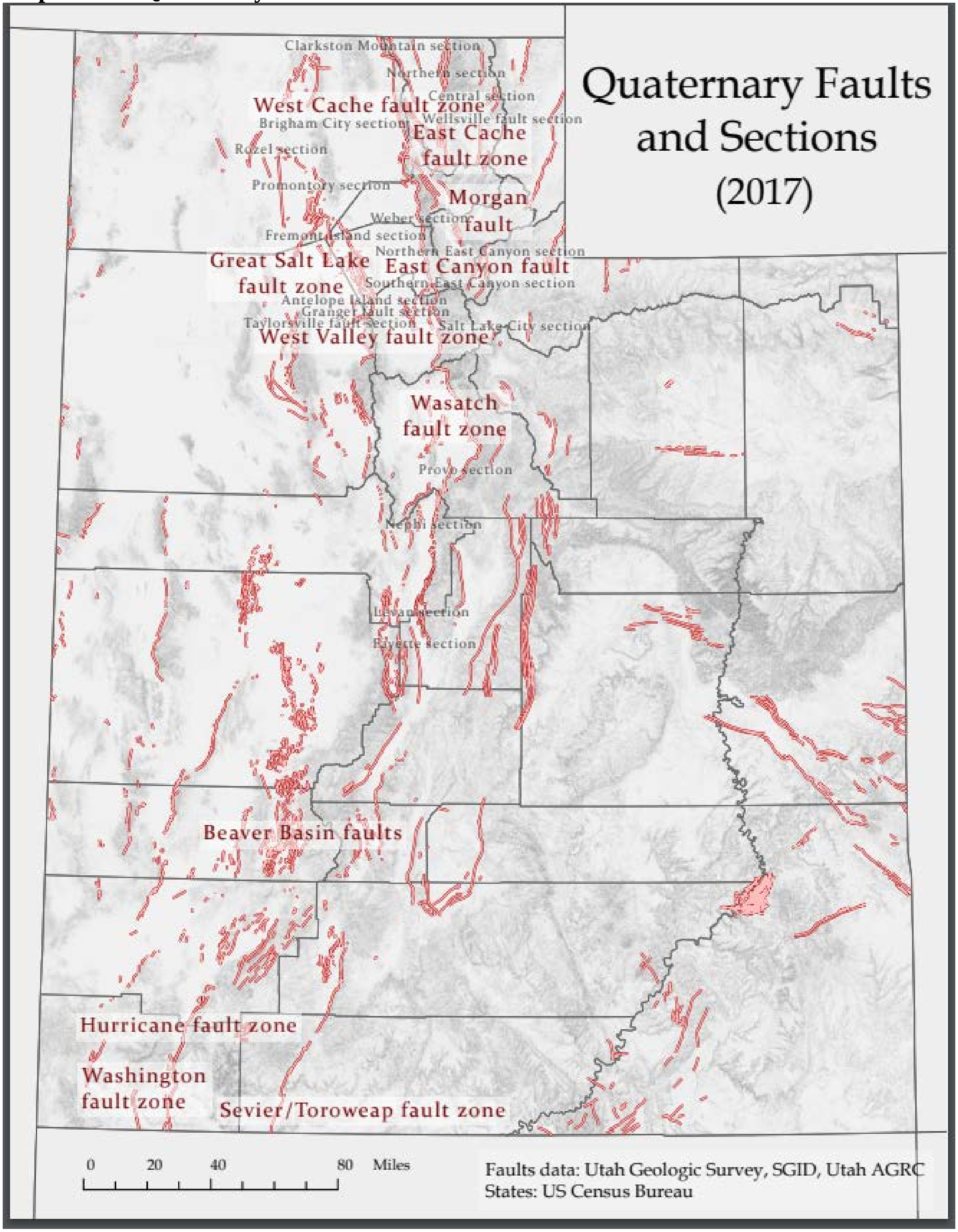
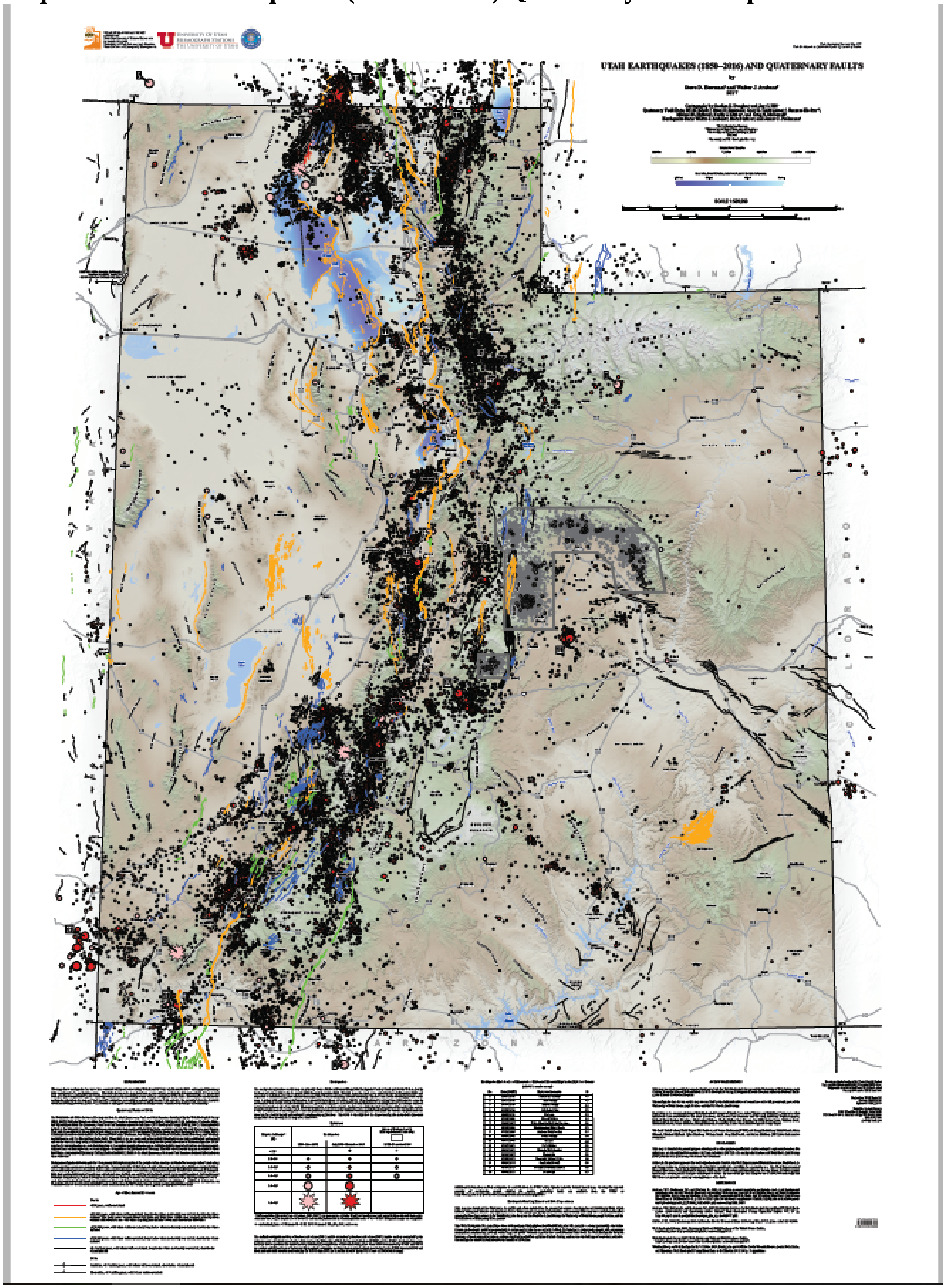
[5] https://ugspub.nr.utah.gov/publications/maps/m-277.pdf

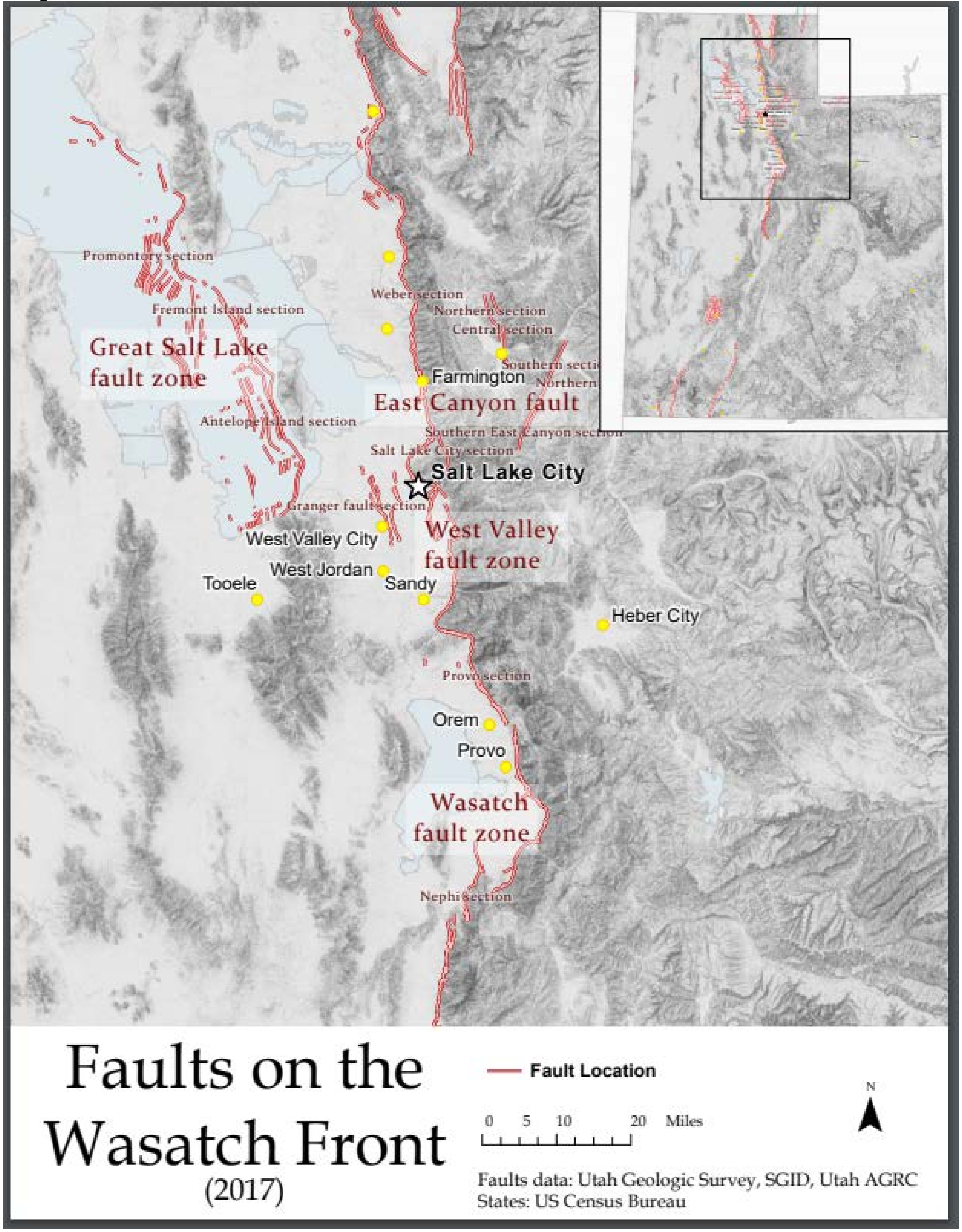
Map 1. Utah Quaternary Faults and Sections



Map 2. The Utah Earthquakes (1850 to 2016) Quaternary Fault Map



Map 3. Faults on the Wasatch Front



Faults data: Utah Geologic Survey, SGID, Utah AGRC
States: US Census Bureau

The 350-km-long Wasatch Fault Zone (WFZ) consists of 10 segments that are thought to have ruptured repeatedly and independently in large magnitude (M ≥ 6.75) earthquakes. The five central segments from north to south are the Brigham City, Weber, Salt Lake City, Provo and Nephi segments. These central segments are thought to be the most hazardous, because each segment has had multiple large Holocene (past 11,700 yrs.) earthquakes that have produced surface rupture. Detailed geologic investigations at 23 paleo seismic sites on these segments have yielded data on the timing of past earthquakes and measured single-event fault displacements. The resulting data show that at least four to five earthquakes have occurred on each central segment in the past 6000 years large enough to cause surface rupture. At least 22 surface-faulting earthquakes have ruptured the central segments of the WFZ since approximately 6000 years ago.

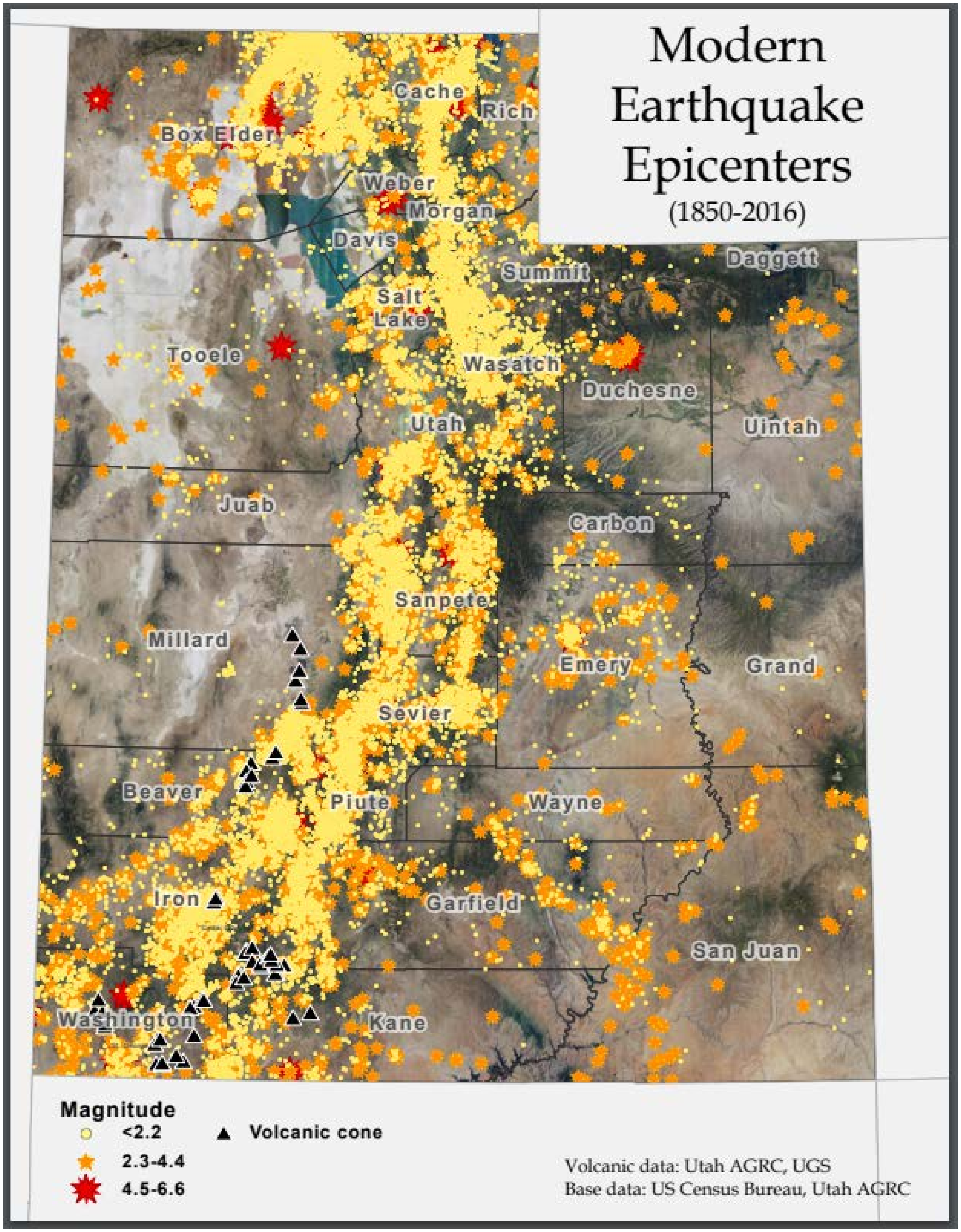
Many other quaternary faults capable of producing significant earthquakes exist in Utah besides the WFZ. Other notable faults include the East and West Bear Lake, East and West Cache, Hurricane, Oquirrh-Great Salt Lake, Sevier-Toroweap, Washington, and West Valley fault zones. However, earthquakes on other faults or background earthquakes the result of tectonic loading may also occur within and surround the state of Utah.

Types of Primary Earthquake (Seismic) Hazards

Ground Shaking

Ground shaking is a sudden motion or trembling of the Earth as stored elastic energy is released by fracture and movement of rocks along a fault. Anticipated ground shaking at a particular site is part of the structure design process detailed in the 2015 *International Building Code* (IBC) and *International Residential Code* (IRC) adopted statewide in Utah. The anticipated ground shaking is determined from U.S. Geological Survey National Seismic Hazard Maps that are part of the IBC and IRC codes.

Map 4. Modern Earthquake Epicenters 1850- 2016



Volcanic data: Utah AGRC, UGS
Base data: US Census Bureau, Utah AGRC

Types of Secondary Earthquake (Seismic) Hazards and Effects

Surface Fault Rupture

Surface fault rupture is a displacement of the ground surface along a tectonic fault during an earthquake that often results in a steep scarp. Earthquakes greater than about M 6.5 are required to produce surface fault rupture in the Intermountain West. Fault displacements can easily exceed infrastructure design, resulting in failure and collapse. The UGS publishes surface fault rupture hazard maps that show the location of fault traces at the surface and appropriate special study zones where the UGS recommends a surface fault rupture investigation be performed before development. Hazard ordinances adopted by the cities of Cottonwood Heights, Draper, Holladay, and Salt Lake, and the counties of Salt Lake, Morgan, Utah and Wasatch incorporate these UGS hazard maps.

Surface fault rupture investigations are critical for determining the hazard. However, performing a surface-faulting investigation and adherence to ordinances and guidelines does not guarantee safety. Significant uncertainty is often present due to limited paleo seismic data related to the practical limitations of conducting such investigations (epistemic uncertainty), and natural variability in the location, recurrence, and displacement of successive surface-faulting earthquakes. Aleatory variability in fault behavior cannot be reduced, therefore, predicting exactly when, where, and how much ground rupture will occur during future surface-faulting earthquakes is not possible. New faults may form, existing faults may propagate beyond their present lengths, and elapsed time between individual surface-faulting earthquakes can vary by hundreds or thousands of years and be affected by clustering, triggering and multi- or partial-segment ruptures. For those reasons, developing property near hazardous faults will always involve a level of irreducible, inherent risk.

Liquefaction

Liquefaction is a sudden, large decrease in shear strength of a saturated sandy soil caused by a temporary increase in soil pore water pressure during an earthquake and subsequent collapse of soil structure, resulting in sand boils, differential foundation settlement, lateral spread landslides, and localized shallow flooding. Liquefaction can cause buildings to tip and settle, roads to crack, deform and flood, buried storage tanks and other underground infrastructure to rise up towards the surface and other types of damage to buildings and infrastructure. Significantly large areas along the densely populated Wasatch Front are subject to liquefaction and/or lateral spreading, among other areas in Utah. The 1934 M 6.6 Hansel Valley and 1962 M 5.7 Cache Valley earthquakes caused liquefaction and property damage in Utah. In addition, the 1992 M 5.5 St. George earthquake (Christenson, 1995) caused liquefaction and the 2010 M 4.5 Randolph earthquake is one of the smallest magnitude earthquakes known worldwide to have caused liquefaction.[6]

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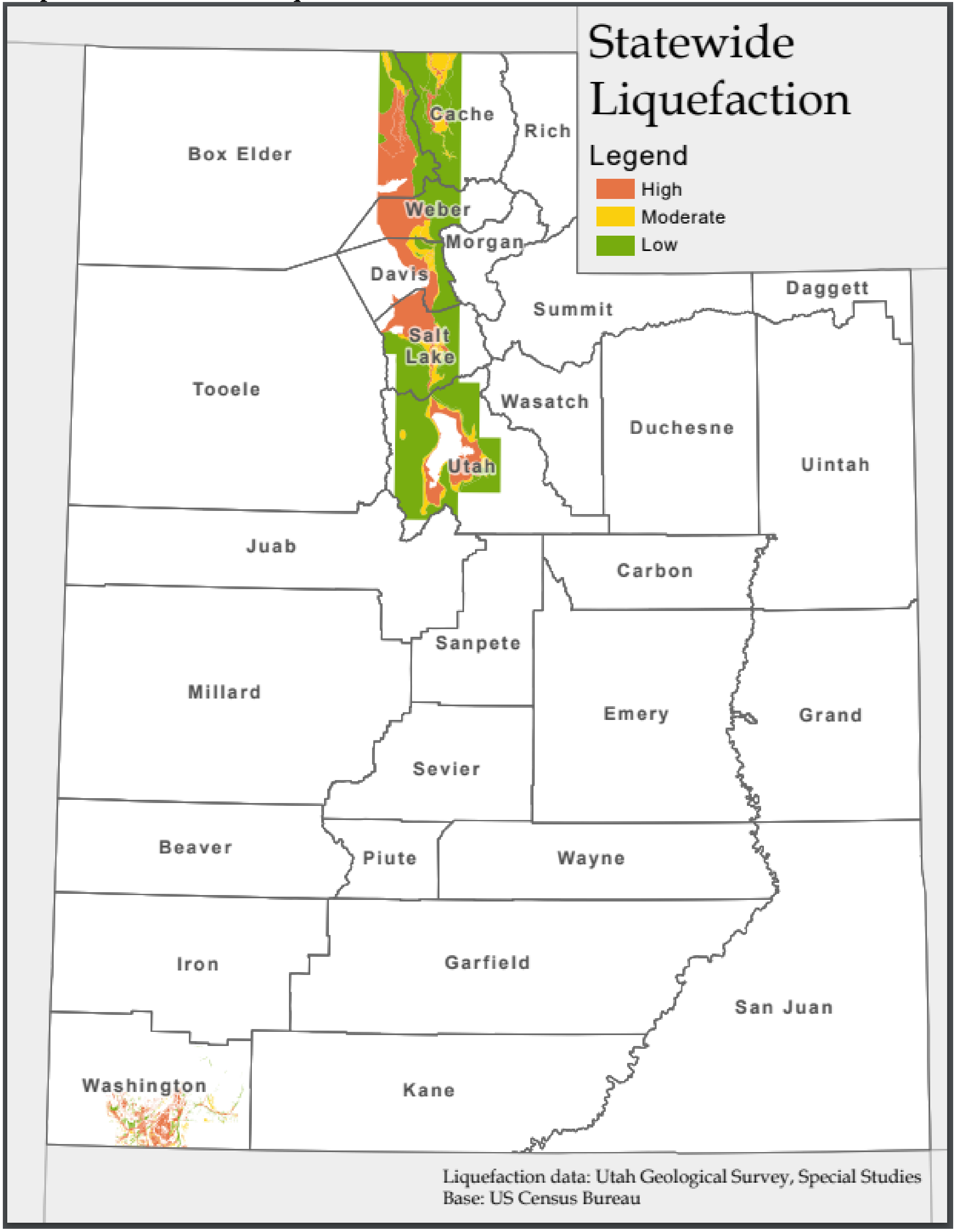
[6] https://geology.utah.gov/map-pub/survey-notes/liquefaction-in-the-april-15-2010-m-4-5-randolph-earthquake/

Map 5. Utah Statewide Liquefaction



Liquefaction data: Utah Geological Survey, Special Studies Base: US Census Bureau.

Liquefaction occurs when water-saturated sandy soils are subjected to earthquake ground shaking. When soil liquefies, it loses strength and behaves as a viscous liquid like quicksand rather than as a solid. This can cause buildings to sink into the ground or tilt, buried tanks to rise to the surface, slope failures, lateral spreading when nearly level ground shifts, surface subsidence, ground cracking and sand blows. Liquefaction has caused significant property damage in many earthquakes and is a major hazard associated with earthquakes in Utah. The 1934 Hansel Valley and 1962 Cache Valley earthquakes caused liquefaction resulting in large prehistoric lateral spreads at many locations along the Wasatch Front. The valleys of the Wasatch Front are especially vulnerable to liquefaction because of susceptible soils, shallow ground water and relatively high probability of moderate to large earthquakes. Two conditions must exist for liquefaction to occur: (1) the soil must be susceptible to liquefaction loose, water-saturated, sandy soil, typically between 0 and 30 feet below the ground surface and (2) ground shaking must be strong enough to cause susceptible soils to liquefy.

Seiches

A seiche is a standing (oscillating) wave in a body of water that is at least partially enclosed and can be induced by earthquakes and other energy sources. These waves can damage near-shore infrastructure, such as docks, buildings, utilities, etc. and cause localized flooding of low-lying areas. Bear Lake, Great Salt Lake and Utah Lake are all near quaternary faults capable of producing a seiche during an earthquake. Quaternary faults capable of producing tsunamis are also present beneath these lakes.

Tsunamis

A tsunami is a series of waves in the ocean or a lake caused by the displacement of a large volume of water, such as from underwater fault rupture or landslides into the water. While not a widespread geologic hazard in Utah, a significant hazard exists on and adjacent to Bear Lake, Great Salt Lake and Utah Lake that all contain quaternary faults capable of producing a tsunami during an earthquake with subaqueous fault rupture.

Tectonic Deformation

Tectonic deformation is the lowering and tilting of a valley floor on the down dropped side of a fault during an earthquake and commonly causes localized flooding and gravity flow utility failure. The location of the northern end of the Jordan River in Salt Lake Valley has moved significantly several times in the geologic past, likely the result of tectonic deformation.

Earthquake-Triggered Landslides and Rock fall

Landslides and/or rock fall are often triggered by earthquake ground shaking. The 1988 M 5.3 San Rafael Swell earthquake produced significant rock fall in the region. See the landslides section for more information.

The 2008 M6.0 Wells, Nevada Earthquake – Lessons for Utah

The February 21, 2008 M 6.0 Wells, Nevada earthquake occurred at 6:16 a.m. in a rural town in northeastern Nevada with a population of 1,657 people. The earthquake was felt throughout eastern Nevada, southern Idaho, and northwestern Utah, including the Wasatch Front region of Utah. There were 1,883 responses from the earthquake in six states on the U.S. Geological Survey (USGS) Did You Feel It? Website.[7] The earthquake caused minor damage to over 40, and major damage to 17 commercial and government buildings, along with damage to over 60 chimneys (10-15%) and widespread non-structural damage such as windows, drywall, furniture and building contents for a total estimated damage of $10.5 million.

The event initiated the quick response of both state and federal scientific and emergency-management agencies. Within hours of the event, Nevada and Utah state emergency operations centers were activated and coordinating. Seismic details of the main shock and aftershocks were available through the Nevada Seismological Laboratory (NSL) and USGS National Earthquake Information Center. Geologists from Nevada Bureau of Mines and Geology (NBMG), the UGS and University of Nevada Reno Center for Neotectonics Studies were field-checking known quaternary faults near the earthquake's epicenter. Within days of the event, a UGS technical clearinghouse website organized early earthquake information. Shortly thereafter, an NBMG earthquake portal provided a comprehensive central location for maps, photographs, preliminary damage reports and reconnaissance field reports and seismologists from the University of Utah, NSL, and USGS had deployed temporary seismic instrument arrays.

The predominately unreinforced brick construction of many of the residential, commercial and governmental buildings and the fragile economic conditions in Wells are very similar to those found in many rural Utah communities. Building and infrastructure damage from a similar event in rural Utah will likely be very similar to Wells, along with disruptions to employment, schools, supplies, utilities and other essential amenities. Learning from the experiences of Wells can help Utah communities better prepare for, respond to and recover from a damaging earthquake or other geologic hazard event. In addition, the Wells earthquake also demonstrated the effectiveness of how multiple agencies responded to an event far from their normal base of operations in a relatively remote area in winter conditions.

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[7] (https://earthquake.usgs.gov/data/dyfi/)

Utah Earthquake Probabilities

Since the late 1960s, abundant paleo seismic data on the timing and size of prehistoric surface-rupturing earthquakes have been collected on the WFZ and other faults in Utah's Wasatch Front region, which extends into southeastern Idaho and southwestern Wyoming. Motivated in part by the recent development of improved methods to analyze paleo seismic data, the Working Group on Utah Earthquake Probabilities (WGUEP) was formed in January 2010, under the auspices of the UGS and the USGS, to evaluate the probabilities of future occurrence of moderate-to-large earthquakes in the Wasatch Front region. The working group consisted of 14 geologists, seismologists and engineers affiliated with diverse federal, state, academic and consulting organizations.

The WGUEP's goal was to develop probabilistic earthquake forecasts for the Wasatch Front region that include: (1) combined time-dependent and time-independent probabilities of large earthquakes for the five central segments of the WFZ and two segments of the Great Salt Lake fault zone, (2) time-independent probabilities for less well-studied faults, and (3) estimates of the time-independent probabilities of background earthquakes not associated with known or mapped faults in the M 5.0 to 6.75 range.

The WGUEP provided the forecasts with the hope that they will help heighten the public's awareness and understanding of the region's seismic hazards, just as the forecasts of the Working Groups on California Earthquake Probabilities (WGCEP) have successfully done. The consensus-based time-dependent and time-independent earthquake probabilities in the Wasatch Front region are not only useful for regional hazard analyses, they also give a robust basis for site-specific probabilistic seismic hazard analyses (PSHAs) for the safe design and evaluation of critical structures and facilities. In addition, the time-dependent probabilities for fault ruptures can be incorporated into the PSHAs that will support urban seismic hazard maps planned by the USGS for the Wasatch Front region. Additionally, earthquake forecasts can aid in developing public policies leading to more effective, sustained earthquake mitigation efforts for the Wasatch Front region.

Based on the inputs summarized above, the probability of one or more large ($M \geq 6.75$) earthquakes occurring in the Wasatch Front region in the next 50 years (2014 to 2063) is 43%. This regional probability is for earthquakes on all the characterized faults. The probability of one or more earthquakes of M 6.0 or larger in the Wasatch Front region in the next 50 years is 57%. In addition, the probability of one or more earthquakes of M 5.0 or larger in the Wasatch Front region in the next 50 years is 93%.

A significant contribution to these total probabilities comes from the WFZ and Oquirrh-Great Salt Lake fault zone. The total probability of at least one earthquake of M 6.75 or larger on either of these two fault zones is 23% in the next 50 years. The total probability from the other modeled faults is 25% due in part to some significant contributions from faults with higher slip rates such as the Eastern Bear Lake and Stansbury fault zones. The Eastern Bear Lake fault has a probability of 6.3% for one or more earthquakes of M 6.75

or larger in the next 50 years. The 50-year probability is 34% for one or more earthquakes of M 6.0 or larger on the other faults. For background earthquakes of M 6.0 or larger on buried or unknown faults, the 50-year probability is 14%. Figure xx shows the 50-year probabilities for earthquakes of M 6.75 or larger on selected fault segments. For example, the probabilities on the Salt Lake City, Brigham City, Provo and Weber segments are 5.8%, 5.6%, 3.9%, and 3.2%, respectively. The 50-year probability on the Nephi segment is relatively low at only 1.8% because its most recent rupture occurred only about 300 years ago. Although these individual probabilities might seem small, the total probability for an earthquake of M 6.75 or larger somewhere on the WFZ in the next 50 years is 18%. In the next 100 years, the probability increases to 33%. Such a large earthquake occurring anywhere along the WFZ will result in considerable damage to communities in the Wasatch Front region and their economies.[8]

Considering that the average age of Utah's citizens is the youngest in the nation with a median age of 29.2 years, there is a realistic chance that many current residents of the Wasatch Front region will experience a large earthquake in their lifetimes. Preparing for earthquakes requires an awareness that even earthquakes in the M 5 range can cause significant localized damage in urbanized areas and the probability of earthquakes of this size occurring in the coming decades in Utah is very high.

Landslide Hazards

A landslide is the downslope movement of rock, soil, and/or debris (landslides, debris flows, rockfalls, etc.), in which much of the material moves as a coherent or semi-coherent mass with little internal deformation, and movement occurs on either a curved (rotational slide) or planar (translational slide) rupture surface. Occasionally, individual landslides may involve multiple types of movement if conditions change as the displaced material moves downslope. For example, a landslide may initiate as a rotational slide and then become a translational slide as it progresses downslope. Slope failures are classified by their movement: falls, slides, topples or flows and by the type of material: rock, debris and soil.

According to the USGS, landslides are a widespread geological hazard that occur in all 50 states, however, the coastal states and the Intermountain West, including Utah, are the primary regions of landslide activity. Nationally, landslides result in 25 to 50 deaths annually and cause approximately $4.8 billion (2017 dollars) in damage. In 2014, an approximately 650-foot-high slope near Oso, Washington, underlain by glacial till and lacustrine lake deposits with a history of previous landslides failed and rapidly inundated a neighborhood claiming the lives of 43 people, making it the deadliest landslide in U.S. history.[9] Although landslide losses in Utah are poorly documented, Francis Ashland, of the Utah Geologic Survey estimated losses from damaging landslides in 2001 exceeded $3 million, including the costs to repair and stabilize hillsides along state and federal

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[8] Earthquake Engineering Research Institute, Utah Chapter, 2015

[9] Keaton and others, 2014

highways. This estimate remains the most recent landslide damage estimate for Utah, however, total losses during that year are unknown because of incomplete cost documentation of landslide activity.

Landslides include both natural and human-induced variables, making landslide-hazard investigation a complex task. Slope instability can result from many factors, including geomorphic, hydrologic and geologic conditions and modification of these conditions by human activity. The frequency and intensity of precipitation and seismicity are also contributing factors. Existing landslides can represent either marginally stable slopes or unstable slopes that are actively moving. Site conditions must be evaluated in terms of proposed site modification associated with structure size and placement, slope modification by cutting and filling, and changes to groundwater conditions.

Many Utah landslides are considered dormant, but recent slope failures are commonly reactivations of pre-existing landslides, suggesting that even so-called dormant landslides may continue to exhibit slow creep or are capable of renewed movement if stability thresholds are exceeded. Past slope failures can be used to identify the geologic, hydrologic and topographic conditions that may reactivate existing landslides and initiate new landslides. In addition to natural conditions, human-induced conditions, such as modification of slopes by grading or a human-caused change in hydrologic conditions, can create or increase an area’s susceptibility to landslides.

Slope steepness is an important factor in slope stability. In Salt Lake County, 56 percent of all slope failures occurred on hillsides where slopes range between 31 and 60 percent, which promoted Salt Lake County to lower the maximum allowable buildable slope from 40 percent to 30 percent in 1986.[10]

The distribution of landslides in Utah is also dependent on geology, topography and climate. Landslides are most numerous in a zone stretching from the northern Wasatch Front and back valleys southwestward to the St. George area. This zone contains weak rock types, steep slopes and generally high annual precipitation in the state.

Slope failures occur because of an increase in the driving forces like weight of slope and slope gradient or a decrease in the resisting forces like friction or the strength of the material making up a slope. Geology, topography, water content, vegetative cover and slope aspect are important factors of slope stability. In Utah many landslides are associated with rising ground-water levels due to rainfall, snowmelt and landscape irrigation, therefore they typically occur in March, April and May.

Urban development in and along hillside areas increase the number of people threatened by landslides events each year. Many factors contribute to overall landslide vulnerability including local weather, soil moisture, duration and intensity of precipitation, wildfire history and the construction of structures.

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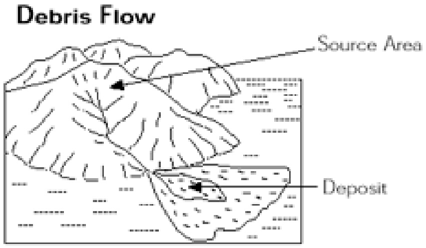
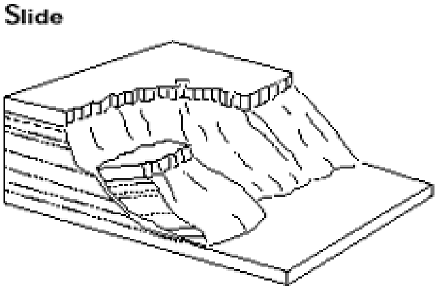
[10] Lund, 1986

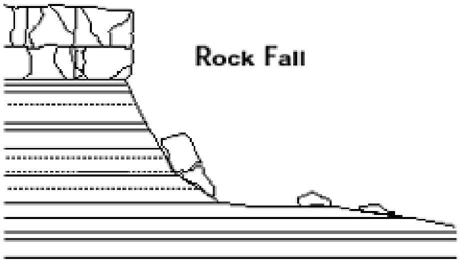
Figure 1. Three Common Types of Landslides in Utah



Debris flows consist of sediment-water mixtures that flow down a streambed or hillside, commonly depositing sediment at canyon mouths in fan like deposits known as alluvial fans.



Slides are down slope movements of soil or rock on slopes.



Rock falls consist of rock(s) falling from a cliff or cut slope and are very common in the canyon country of southern Utah. Rock falls typically occur with no warning often during or following storms, periods of snowmelt and earthquakes.

Conditions That Make Slopes More Susceptible to Landslides

- Discontinuities including faults, joints, bedding surfaces.
- Massive materials over soft materials.
- Orientations of dip slope or bedding planes that dip out of slope.
- Loose structure and roundness.
- Additional weight to the head of a slide such as rain, snow, landslides, mine waste piles, buildings, leaks from pipes, sewers, canals, and construction or fill materials.
- Ground shaking earthquakes or vibrations.
- Increase in lateral spread caused by mechanical weathering.
- Removal of lateral support.
- Human activities such as cut and fill practices, quarries, mine pits, road cuts and lowering of reservoirs.
- Removal of underlying support including under cutting of banks in a river.
- Increase in pore water pressure consistent with snow melt, rain, and irrigation.
- Loss of cohesion.

In the United States, it is estimated that the total dollar losses from landslides annually are between one and two billion dollars. Landslides result in extremely high monetary losses in other countries too, but there are no exact figures because no agency tracks or reports landslide losses. According to the US Geological Society (USGS) between 25 and 50 people die in landslides in the US annually.

Types of Landslide Hazards

Landslides

A landslide is a mass-movement involving the downslope transport under gravitational influence of soil and rock materials.

Rock fall

Rock fall is a natural mass-wasting process that involves the dislodging and rapid downslope movement of individual rocks and rock masses. The widespread combination of steep slopes capped by well-jointed bedrock makes rock fall among the most common slope-failure types in Utah. Rock fall poses a hazard because falling, rolling and bouncing rocks and boulders can cause significant property damage and be life threatening. At least 15 deaths directly attributable to rock falls have occurred in Utah since 1850.

Rock falls occur where a source of rock exists above a slope steep enough to allow rapid downslope movement of dislodged rocks by falling, rolling, bouncing and sliding. Rock fall sources include bedrock outcrops or boulders on steep mountainsides or near the edges of escarpments such as cliffs, bluffs and terraces. Talus cones and screen-covered slopes are indicators of a high rock fall hazards, but other less obvious areas may also be vulnerable. Slope modifications such as cuts for roads and building pads and clearing slope vegetation for development or from wildfire danger can increase or create rock fall hazards, as can construction of non-engineered and/or poorly constructed rock walls, which are becoming increasingly common in Utah urban areas. Most rock falls originate on slopes steeper than 35 degrees, although rock fall hazards may be found on less-steep slopes.

Rock falls may be triggered by freeze/thaw action, rainfall, changes to groundwater conditions, weathering and erosion of the rock and surrounding material and root growth. Rock fall is the most common type of mass movement caused by earthquakes. Generally, earthquakes greater than M 4.0 can trigger rock falls. In Utah, the 1988 M 5.3 San Rafael Swell earthquake triggered multiple rock falls and the 1992 M 5.8 St. George earthquake caused numerous rock falls in Washington County. However, many rock falls occur with no identifiable trigger. Although not well documented, rock falls in Utah appear to occur more frequently during spring and summer months. This is likely due to spring snowmelt, summer cloudburst storms and large daily temperature variations.

Early recognition and avoiding areas subject to rock fall are the most effective means of reducing rock fall hazards. However, avoidance may not always be a viable or cost-effective option, especially for existing development, and other techniques are available to reduce potential rock fall damage. These may include, but are not limited to, rock stabilization, removal of loose rock (scaling), emplacement of engineered structures and modification of at-risk structures or facilities. Rock-stabilization methods are physical means of reducing the hazard at its source using rock bolts and anchors, steel mesh or shotcrete on susceptible outcrops. Engineered catchment or deflection structures, such as berms or benches, can be placed below source areas, or at-risk structures themselves could be designed to stop, deflect, retard, or retain falling rocks. Conversely, after careful consideration of the hazard, it may be possible to conclude that the level of risk is acceptable and that no hazard-reduction measures are required.

Debris Flows

Debris flows and related sediment flows are fast-moving flow-type landslides composed of a slurry of rock, mud, organic matter and water that move down drainage-basin channels onto alluvial fans. Debris flows generally initiate on steep slopes or in channels by the addition of water from intense rainfall or rapid snowmelt and often occur after rangeland or forest fires. Flows typically incorporate additional sediment and vegetation as they travel down-channel. When flows reach an alluvial fan and lose channel confinement, they spread laterally and deposit the entrained sediment. In addition to being debris-flow-deposition sites, alluvial fans are also favored sites for urban development; therefore, a debris-flow-hazard investigation is necessary when developing on alluvial fans. The hazard investigation may indicate that risk reduction is necessary for sustainable development on the alluvial fan. A debris-flow-hazard investigation requires an understanding of the debris-flow processes that govern sediment supply, sediment bulking, flow volume, flow frequency and deposition. However, a uniform level of acceptable risk for debris flows based on recurrence or frequency/volume relations, such as the 100-year flood or the 2% in 50-year exceedance probability for earthquake ground shaking, has not been established in Utah.

Historical records of sedimentation events in Utah indicate that debris flows are highly variable in terms of size, material properties, travel distance and depositional behavior. Therefore, an elevated level of precision for debris-flow design parameters is not yet possible and conservative engineering parameters and designs must be used where risk reduction is necessary.

Large-volume debris flows are low-frequency events and the interval between large flows is typically deceptively tranquil. The debris-flow hazard on alluvial fans can be difficult to recognize, particularly on alluvial fans that are subject to high-magnitude, low-frequency events. Debris flows pose a hazard very different from other types of landslides and floods due to their rapid movement and destructive power. Debris flows can occur with little warning. Fifteen people have been killed by debris flows in Utah. Thirteen of the victims died in two different night events when fast-moving debris flows allowed little chance for escape. In addition to threatening lives, debris flows can damage buildings and infrastructure by sediment burial, erosion, direct impact and associated water flooding. The

1983 Rudd Canyon debris flow in Farmington deposited approximately 90,000 cubic yards of sediment on the alluvial fan, damaged 35 houses, and caused an estimated $3 million in property damage.[11]

Snow Avalanches
(Covered in the Avalanches section of the State Plan)

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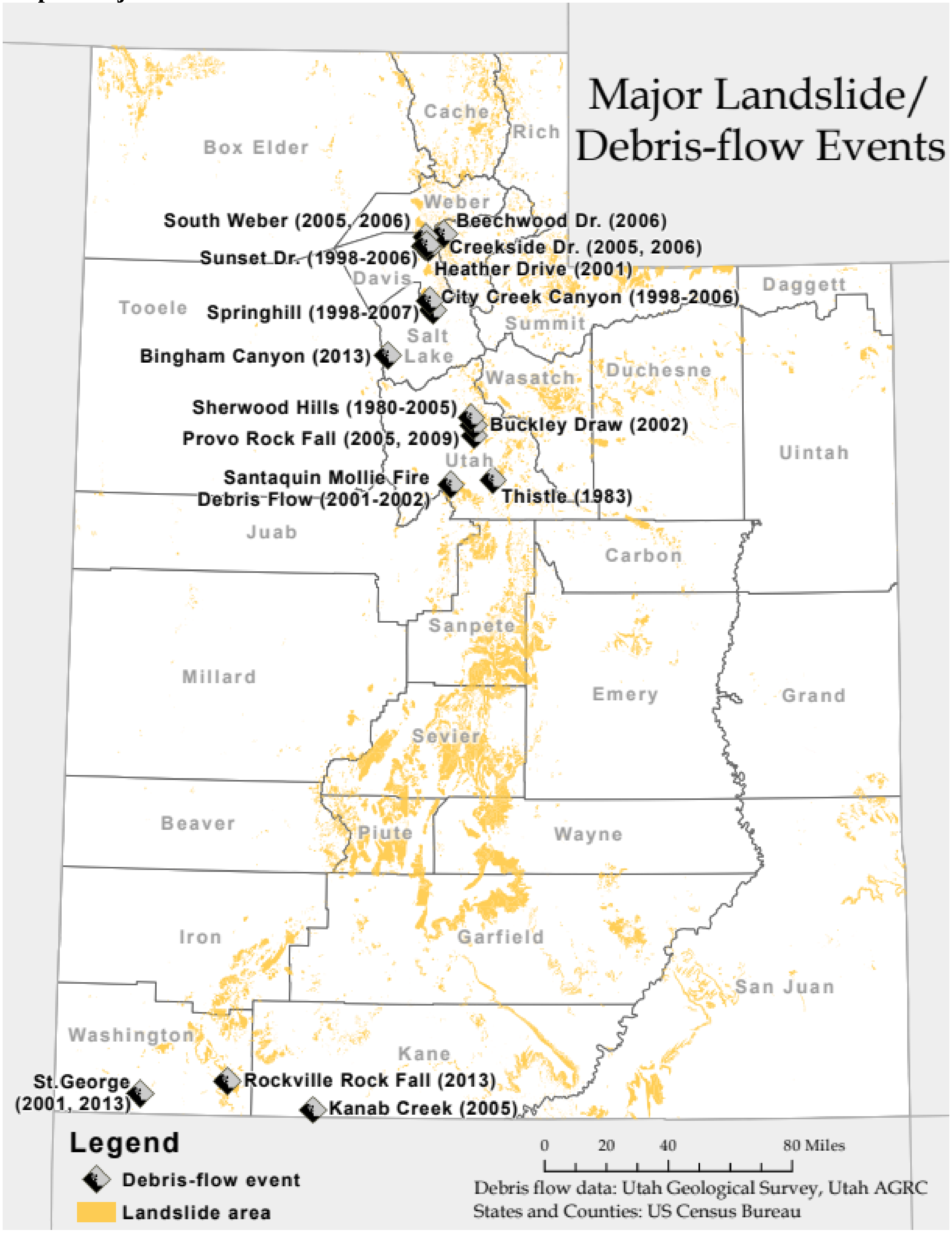
[11] Steve Bowman and Francis Ashland, of the Utah Geologic Survey wrote "The Feasibility of Collecting Accurate Landslide-Loss Data in Utah, Open File Report 410".

Map 6. Major Landslide and Debris-flow Events in Utah 1983 to 2013



Debris flow data: Utah Geological Survey, Utah AGRC
States and Counties: US Census Bureau

Significant and Recent Utah Landslides

Utah has experienced numerous significant landslides, where fatalities occurred, that were costly financially to the land owners and local government and economically damaging to the region. The limited list of Utah landslides below highlights some of the more significant landslides and landslides for which the UGS has also provided emergency response services:

- 1983 Thistle landslide (https://geodata.geology.utah.gov/pages/search.php?search=!collection233)
- 1998 Springhill landslide, North Salt Lake (http://geology.utah.gov/?page_id=6549)
- 2009 Logan Bluffs landslide, Logan (http://geology.utah.gov/?page_id=11722)
- 2010 274 Main Street rock fall, Rockville (http://geology.utah.gov/?page_id=6531)
- 2012 Seeley fire debris flows, Manti-LaSal National Forest (http://wp.me/P5HpmR-2QJ)
- December 2013 368 West Main Street rock fall, Rockville (https://ugspub.nr.utah.gov/publications/reports_of_investigations/ri-273.pdf)
- August 2014 Parkway Drive landslide, North Salt Lake (http://geology.utah.gov/?page_id=17991)
- 2017 Box Elder County flooding-related landslides (https://wp.me/P5HpmR-8hS)
- 2017 Spring Creek Road landslide, Riverdale (https://wp.me/P5HpmR-8gy)
- 2017 Zion National Park rock falls (https://geodata.geology.utah.gov/pages/search.php?search=!collection405)
- 2018 Zion National Park rock falls (https://geodata.geology.utah.gov/pages/search.php?search=!collection393)

Thistle Slide

In 1983, the town of Thistle was destroyed by floodwaters when the Thistle landslide created a natural dam and subsequent reservoir, blocking roads and rail lines. The Marysvale branch of the railroad was never reopened, leaving a large area of central Utah without rail service. Thistle resulted in Utah's first presidential disaster declaration and became the most costly landslide in United States history. Three reports have been issued estimating the cost of the landslide between $200 million and $337 million dollars in 1983.

Courtesy UGS

Heather Drive Landslide

Lake Bonneville sediments in the Layton area are prone to landslides. In 2001, a landslide destroyed three houses in Layton City and forced the relocation of three others. Landslide movement also severed underground utility service to the houses. Total dollar losses for this event have been estimated by various sources to be between $519,800 and $1,092,000 in 2001. This landslide was a partial reactivation of a prehistoric landslide in silt and clay sediments of ancient Lake Bonneville.

Courtesy UGS

Santaquin Mollie Fire Debris Flow

In August of 2001, the 8,000+ acre Mollie Fire burned an area of the Wasatch Range known as Dry Mountain above the city of Santaquin. The bench development area of Santaquin City is located no more than 50 yards from the edge of the fire perimeter on an alluvial fan. The Mollie wildfire caused watershed damaged and elevated the debris flow risk. At approximately 6:45 p.m. on Thursday, September 12, 2002, after nearly a week of intense thunderstorms, the charred earth of the ironically named Dry Mountain produced 10 debris flows. These flows did major damage to several houses and resulted in significant cleanup costs.

Courtesy UGS

Buckley Draw—Springville Fire

The Springville fire started on June 30, 2002 at 7:19 p.m. and burned a total of 2,207 acres above dozens of homes. This burned area heightened the debris flow risk to those homes on the alluvial fans below. At an April 29, 2003 neighborhood meeting, the debris flows in Santaquin were contrasted with the conditions at the Buckley Draw. Plans for trench construction were discussed. A flag notification system and evacuation plan was put in place. A website with updated hazard information, a phone message hotline and a notification procedure alerting the neighborhood chair of any changes in the hazard level was implemented. A practice evacuation drill was held on Saturday, May 10, 2003.

The 1,500 foot long trench/deflection dike was completed on July 28, 2003, by Provo City in conjunction with the NRCS and their Emergency Watershed Protection program. At approximately 3:00 a.m. on September 10, 2003, four separate debris flows were triggered. The newly finished trench worked as designed and routed the second largest flow, preventing property loss and potential life loss. The spreader fences in the debris run-out field distributed the runoff materials and completely contained the debris flow.

Kanab Creek Landslide

On March 12, 2005 at approximately 5:30 p.m. a 100 ft. long by 60 ft. high vertical stream cut along Kanab Creek failed. The resulting landslide occurred within the city limits of Kanab, killing one boy and partially burying two children. This earth fall landslide was most likely the result of long-term gravitational effects on over-steepened, unconsolidated material in the arroyo walls.[12]

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[12] https://geology.utah.gov/hazards/landslides-rockfalls/kanab-creek-landslide/

Courtesy UGS

<u>Provo Rock Fall</u>

On May 12, 2005 at 5:00 p.m. a rock fall destroyed a guest house located in Provo. No fatalities resulted from the rock fall. The rock measured 7 x 5.1 x 4.5 feet and weighed approximately 13 tons. The rock fall is believed to have resulted from a series of significant storms that passed through the Provo area between May 10-12, in which approximately 3.7 inches of mixed rain and snow fell on the area. It was raining at the time of the rock fall.[13]

Courtesy UGS

<u>South Weber Landslide</u>

Around 9:30 p.m. on Sunday, April 9, 2006, a rapidly moving landslide in South Weber broke through the back wall of a house at 7687 South 1650 East, injuring a child inside. The landslide started on a steep slope near a pond in a gravel pit atop a bluff behind the house. Subsequent investigation found evidence of subsurface water flow from the pond to the slope.

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[13] https://geology.utah.gov/hazards/landslides-rockfalls/rock-fall-in-provo-2005/

Courtesy UGS

Water seepage and saturation of materials atop the bluff likely triggered the landslide, but the steep slope, the weight of fill placed on the top of the slope and weak underlying geologic materials were contributing factors. Also, a major rain and snow storm from April 4 -6 dropped approximately two inches of water, likely causing surface and subsurface water levels to rise. After the landslide, the pond was drained to reduce further sliding. The 1650 East landslide and a similar one nearby in 2005 that demolished a barn and blocked South Weber Drive (State Route 60), demonstrate the destructive nature of rapidly moving landslides and the risk of building at the base of steep slopes.

Sunset Drive and Beechwood Drive Landslides

Homeowners along Sunset Drive in Layton recognized in mid-April of 2006 that the Sunset Drive landslide had reactivated. In 1998 landslide movement damaged seven lots and resulted in a house being condemned and demolished. The 2006 movement affected six lots, including two homes. The house at 1843 East Sunset Drive straddles the main scarp, and landslide movement had removed support from beneath part of the foundation. Layton City building inspectors deemed the house unsafe for occupancy due to structural damage and recommended it be moved off the landslide to another location. Utah Geological Survey (UGS) geologists measured a 4-8-foot increase in ground-water levels in and around the landslide between March 16 and April 17, which apparently triggered movement. The 2006 peak ground-water level is a threshold that can be used to predict future landslide movement.

Courtesy UGS

Sunset and Beechwood Drive landslides

The Beechwood Drive landslide occurred a quarter-mile south of the Sunset Drive landslide and reactivated at about the same time. The Beechwood Drive landslide is a reactivation of a pre-existing landslide with no documented historical movement. The landslide's main scarp cuts across the back of five lots and has damaged landscaping in backyards. The landslide also affected the upper part of the proposed Beechwood subdivision phase 6 development. Both the Sunset and Beechwood Drive landslides show how prone some slopes in Layton are to landslide movement.

Creekside Drive Landslide

In Morgan County in 2005 three landslides formed in the Creekside Drive area of Mountain Green, on a northeast-facing slope underlain by pre-existing landslide deposits. In 2006 the three landslides reactivated and two new landslides formed nearby.

Courtesy UGS

Landslide movement left this concrete driveway slab suspended in the air in the Creekside Drive area of Mountain Green, courtesy UGS

Continued movement of the largest of the five landslides forced the evacuation of a severely damaged house at the top of the slide and damaged two others. Damage also occurred to Creekside Drive and utilities beneath the road, disrupting the power and water to the affected subdivision.

Despite favorable subdivision-wide and lot-specific geotechnical studies, landslides occurred within only a few years of development on the pre-existing landslide deposits. Stabilization of the landslides, particularly the largest one, will likely prove costly and technically challenging.

Sherwood Hills Landslide

The Sherwood Hills landslide in Provo is one of several in northern Utah that has undergone repeated movement over the past 25 years. Damage to houses and roads caused by renewed landslide movement was first documented in the early 1980s. The landslide has been systematically monitored since May 1999 when Provo City established survey points on the slide and began using high-precision Global Positioning System (GPS) survey techniques to measure movement. The survey results suggest that the landslide remained active even during the drought years between 1999 and 2004. With the return of wetter-than-normal conditions in 2005, the rate and area of landslide movement increased. By 2006, three houses in the upper part of the landslide had been abandoned, including one built in 2000 and a road had been severely damaged.

Some data suggests that landslide movement is continuous, slowing in the summer to an undetectable rate, and increasing in the late winter and early spring as groundwater levels rise during the snowmelt. The continuing losses due to movement illustrate the potential high costs, both public and private, associated with development on large, pre-existing landslides.

Damage to road in upper part of Sherwood Hills landslide, Provo, courtesy UGS.

City Creek Canyon Landslides

A cluster of historical landslides are visible from the hairpin turn in Bonneville Boulevard lower City Creek Canyon in Salt Lake City. Movement of the largest and most damaging of these landslides has been monitored since June of 1998 by the UGS and the Salt Lake City surveyor. Since that time the toe of the landslide has moved about 24 feet, and the main scarp has offset the ground surface by about the same amount. Like most recurrently active landslides in northern Utah, movement typically occurs between March and June as ground-water levels rise following the snowmelt. Four houses at the top of the slide are threatened and efforts to protect one house have cost in excess of $300,000. In 2006 the landslide reactivated again, moving about 2 feet despite drier-than-normal conditions in Salt Lake City.

Courtesy UGS

Landslides in Northern Utah

Wet conditions in northern Utah have caused some landslides to reactivate along with other types of shallow slope failures. Areas with active landslides in early 2009 include Ogden Valley in eastern Weber County, western Morgan County, southeastern Davis County and Spanish Fork Canyon in Utah County. Examples include reactivation or acceleration of persistently moving historical landslides, minor movement of landslides in highway cut slopes, local highway embankment and rock-wall failures and local shallow slides on steep slopes in pre-existing landslides.

Above-normal precipitation in southeastern Davis County has caused an increase in the rate of movement of the Springhill Landslide in North Salt Lake, resulting in additional damage to homes, roads and buried utilities. The landslide has moved persistently since the late 1990s, severely damaging three houses since 1998. Landslides have also occurred in Ogden Valley and the Snowbasin area of eastern Weber County.

A snowmelt-induced landslide occurred in the front yard of a house in the foothills of Ogden Valley where saturated fill soil slid onto a driveway that crossed the slope. Reactivation of pre-existing landslides crossed by State Route 226 near Snowbasin ski resort caused minor damage to the highway in several locations. In addition, embankment failures along the edge of the highway cause road cracks and pavement settlement.

Landslides often correlate with snowmelt. Additional landslides in Northern Utah include minor movement of the Frontier Drive Landslide in Morgan County, a small landslide in a highway cut slope in Spanish Fork Canyon, Utah County and a new small slide off a steep slope at the head of the Sage Vista Lane Landslide in Cedar Hills also in Utah County. Several landslides that occurred in generally south-facing slopes, including an embankment failure along US-6/89 in Spanish Fork Canyon, may have been caused by relatively rapid snowmelt. For the most part, no damage has resulted from these landslides.

Provo Rock Fall

Around 11:30 a.m. on April 11, 2009, a rock fall impacted the area of 1500 North and 1550 East in Provo, Utah. The rock falls occurred shortly after an April 8-9 storm that dropped 1.5 inches of precipitation in less than 18 hours at the Cascade Mountain snowpack Telemetry (SNOTEL) site, 3 miles southeast of the rock-fall area. Impact craters (bounce marks) evident on the slope above the houses indicate several rocks traveled downslope and likely achieved high velocities as they bounced and rolled.

Boulder that damaged the vacant house at 1496 North 1550 East, Provo. Boulder is estimated to be 4x5x4 feet, photo courtesy of the Provo Fire Department.

One boulder damaged the outside of a playhouse located at 1522 North 1550 East and another larger boulder severely damaged a vacant house at 1496 North 1550 East. These incidents occurred one lot north of the May 12, 2005 “Y” Mountain rock fall. At 1496 North 1550 East a boulder bounced over the back fence and into the house damaging the ceiling and crashed through a wall before falling through the floor into the garage.

The source of the rock falls in both 2005 and 2009 is a cliff band in the Mississippian Deseret Limestone on “Y” Mountain about 2,600 vertical feet above the houses. Numerous large rocks from prehistoric and historical rock fall events are scattered throughout the neighborhood and on the hillside above, indicating that these lots are in a high rock fall hazard area. Although the occurrence of this rock fall does not necessarily indicate a heightened rock fall hazard under present conditions, rock falls are possible in this area at any time.

Rockville Rock Fall

The rock estimated to be about 21 x 17 x 17 feet and weighing about 450 tons fell from the upper slope of Rockville Bench colliding with a large stationary boulder at the base of the slope and shattering into numerous smaller fragments damaging several outbuildings, two cars and a house. Although people were home at the time, no one was injured. The rock fall occurred shortly after a protracted storm event on February 5-9, 2010 that produced 1.38 inches of rain at the Zion Canyon RAWS station, 4.5 miles northeast of Rockville.

The rock fell 280 vertical feet with a slope distance of 500 feet before colliding with the other boulder. Debris ejected from the impact measured up to 9 feet in dimension and traveled an additional 180 feet. The rock fall originated from the Shinarump Conglomerate Member of the Triassic Chinle Formation that caps Rockville Bench. The rock originally detached from the Shinarump ledge, traveled about 40 feet, and came to rest on a steep slope formed on the upper Moenkopi Formation where it remained for at least 17 years.

The rainstorm prior to the rock fall likely caused material beneath the rock to erode leading to the rock slide. The fall occurred less than 2000 feet west of where another large rock severely damaged a home in Rockville in October 2001. A second large talus boulder remains on the slope along with numerous large boulders along the base of the Rockville Bench that pose a potential hazard to several homes in the area. The Rockville rock fall does not necessarily indicate a heightened hazard, rock falls in this area are possible at any time and typically occur with no warning often during storms, periods of freeze-thaw and earthquakes.

Another rock fall occurred in Rockville on December 12, 2013. A massive boulder the size of a tractor came loose at the top of a cliff near Zions National Park and tumbled down the mountain, crushing a home and killing two people inside. The UGS attributes the movement of the boulders to a week of severe weather, several freeze-thaw cycles and considerable moisture.

Courtesy UGS

Springhill Landslide

UGS has been monitoring conditions at the Springhill landslide in North Salt Lake, Davis County since 1998. In the late 1990s residents began noticing cracking and other distress related to relatively minor movement of the landslide. By 1998 a house at address 160 Springhill Drive that straddled the northern boundary of the landslide was severely damaged and condemned and several houses along Valley View Drive (formerly 350 East) and Springhill Circle also sustained damage.

Courtesy UGS

Little movement occurred during a dry period between 1999 and 2004. The rate of movement accelerated during the wet year of 2005 and has increased every year with above average moisture contributing to damage and distress on Springhill Drive, particularly to houses in the upper and lower parts of the landslide.

The Springhill landslide is about 720 feet long and about 290 feet wide where it intersects with Springhill Drive. The local relief (change in elevation) is about 150 feet and the average slope of the landslide is approximately 21 percent with the ground rising 21 feet over a distance of 100 feet. The depth of the landslide varies along its length. The landslide is approximately 48 feet deep and likely deeper than 70 feet beneath Springhill Drive on the northern edge of Springhill Circle. The landslide is shallower along its southern edge and in the head and toe.

The City of North Salt Lake worked with DEM and FEMA to obtain PDM and HMGP grants to purchase the properties affected by this landslide. By 2013 the houses in the affected area of the landslide were demolished and North Salt Lake had turned the area into open space.

St. George Rock Fall

At around 3:00 AM on January 19, 2013, a 12 x 9 foot boulder dislodged from sandstone Foremaster Ridge and crashed into a resident’s house seriously injuring a woman who was sleeping on her bed. The cause of the rock fall has been attributed to a 40,000 gallon severe water leak associated with a house atop the ridge.

Bingham Canyon Landslides

Two landslides occurred in 2013 at Rio Tinto's Bingham Canyon Mine. The first occurred on April 10, 2013 at 9:30 PM and moved around 65-70 million cubic meters of dirt and rock down the side of the mining pit. Officials at the mine anticipated the slide and took precautions. It is historically the largest landslide in the United States not connected to volcanism. On September 11, 2013 100 workers were evacuated when a second, smaller landslide occurred. No injuries occurred during either landslide.

Courtesy UGS

Parkway Drive Landslide

At about 6:00 a.m. on August 5, 2014 a large landslide sent 300,000 to 400,000 cubic yards down the mountain to Parkway Drive in North Salt Lake, Davis County when an engineered slope failed. The reclaimed slope had been part of an aggregate mining operation in the 1990s that had been partially developed into the Eaglepoint subdivision. The resulting 60-foot scarp 500 feet wide and 500 feet long moved downhill several tens of feet impacting the construction of several houses along the south side of Parkway Drive and earthwork related to building lot development at the crest. A home at 739 Parkway Drive was pushed off its foundation and destroyed and the southeast corner of one of the tennis court facilities at the Eagle Ridge Tennis and Swim Club sustained structural damage. Another resident's backyard along the left flank of the landslide and a recreational trail that crossed the slope were carried away by the landslide. For a short time after the slope failure, 27 homes were evacuated while the landslide was evaluated by city officials, consultants and the UGS.

Courtesy UGS

As part of the response to the original slope failure, the Parkway Drive landslide was remediated from April to December of 2015. The remediation included regrading much of the slope to lower its overall steepness, and installation of a drainage system to collect water from the slope and transport it off the landslide to the local storm drain system. Parts of the lower portion of the landslide were not remediated due to on-going legal issues.

During visits to the site beginning in spring 2016, UGS observed several indications that lower portions of the original landslide were in danger of reactivating. Areas identified included a steep slope on the West side above a home at 745 Parkway Drive and a larger failure on the East side above Eagle Ridge Tennis and Swim Club's parking lot and tent. A part of the original 2014 landslide located behind 745 Parkway Drive that was not remediated in 2015 reactivated shortly after local snow melt in 2016.

In May 2016 the Western slide measured approximately 70 feet wide and extended about 90 feet from scarp to toe. Monitoring equipment placed downhill from the scarp continues to record downslope movement. UGS observed features that suggest a reactivation of part of the original slide above the tennis club occurring on a steep slope that marks the toe of the original landslide. Water has been observed flowing onto the parking lot from the landslide toe and displaced boulders have toppled concrete blocks of the retaining wall constructed at the base of the toe. Since initial observations, the main scarp of this reactivation has grown to an estimated 6 to 7 feet in height. Extension at the scarp has resulted in separation of a drainage pipe designed to carry water off the landslide to the local city storm drain system on Parkway Drive.

The main scarp extends downslope along the western flank of the failure where it transitions to ground cracking, some as large as 10 feet deep suggesting a possible deep seated reactivation, perhaps along the original landslide basal slide plane. In addition to the main scarp, USG observed abundant ground cracks and minor internal scarps near the top of the steep slope above the tennis court parking lot and tent representing a non-remediated portion of the toe of the original landslide.

Spring Creek Road Landslide Riverdale

The Spring Creek Road landslide in Riverdale, Utah is on a steep 200 foot bluff above the Weber River floodplain. The quick-moving landslide initiated on November 19, 2017 as a the water-saturated lower half of the slope dislodged 10 to 15 feet of organic-rich soil and unconsolidated silty sand composed of deltaic deposits from historic Lake Bonneville. The slide flowed onto the pasture below extending approximately 270 feet at an average depth of about 4-7 feet. Landslide activity in this area is related to spring flow emanating from several points approximately halfway up the bluff. The springs continually erode material within the source area depositing it on the pasture below and burying buildings and horse property.

Courtesy Davis County Sheriff's Drone

The initial evacuation area extended about 250 feet up the slope East of Spring Creek Road, which is located at the base of the slope. After the initial event, several major and many minor slides continue to expand the upper boundary of the landslide.

Expansion of the landslide on the upper part of the slope resulted in Riverdale City enforcing a mandatory evacuation of three houses at the top of the slope along the west side of 600 West on November 28, 2017 and a voluntary evacuation of a fourth house, located to the south, in early March 2018. Riverdale City contracted GSH Geotechnical to drill three boreholes in 600 West to provide groundwater elevation data and slope movement measurements.

2017 Flooding and Landslides in Box Elder County

February 7-27, 2017 weather systems moving through northern Utah brought over four inches of rain and temperatures 20 degrees above normal. The combination of rain and above-normal temperatures quickly melted the deep, low-elevation snowpack causing flooding and landslides. In the Tremonton area of Box Elder County this abrupt change in winter weather caused overland flooding, riverine flooding along the Bear River and landslides. Overland flooding and a rise in shallow groundwater levels flooded fields, roads, basements and caused septic drain systems to malfunction. The area experienced similar problems during the record wet year of 1983.

Courtesy Pete Clark

Flooding and the resulting damage overwhelmed the capabilities of local jurisdictions and on February 14, 2017 Box Elder County declared a local emergency and emergency management officials invited UGS to assist in evaluating landslide problems. On March 31, Governor Herbert declared a State of Emergency and on April 6, requested a Presidential Disaster Declaration. On April 21, President Trump signed a Disaster Declaration for Public Assistance for $5.98 million for Box Elder and Cache Counties.

The February 2017 weather event triggered numerous landslides in the bluffs above the Bear River threatening houses and roads. The river bluffs originally formed as the water level of ancient Lake Bonneville declined to modern Great Salt Lake levels and the Bear River incised into the lake bed sediments. River erosion formed large meandering bends and river bluffs 50 to 120 feet high. All of the Box Elder County landslides observed in 2017 are reactivations of preexisting landslides with historical movement. The snowmelt and rain event appear to have raised shallow groundwater levels, saturating landslides and triggering movement that lasted from mid-winter into early spring 2017.

The UGS monitored landslide movement and advised local officials on landslide risk and associated hazards on three landslides located at 10800 North 4400 West, 9050 North River Road and 7200 North 4600 West.

The 10800 North 4400 West landslide damaged a county road when water from snowmelt and rain caused overland flooding. On May 2, 2017, the landslide main scarp was 9.5 feet from the road at its closest point. The landslide removed lateral support for the roadway embankment and the road will likely eventually fail due to this lack of support.

The 9050 North River Road landslide threatened a road in Elwood City. The landslide was only 50 to 70 feet high but extended 1700 feet along the river bluff with the main scarp 6.5 feet from the road at its closest point compromising the road's lateral support and impeding the access road to Hansen Park, while exposing an underground telephone cable.

The 7200 North 4600 West landslide directly threatened one house and advanced a few feet closer to just 14 feet away from the structure in 2017 so it was abandoned as a safety precaution. This lower landslide is at river level and is under water when the Bear River is at flood stage. Flood conditions in February 2017 likely played a role in triggering landslide movement.

A fourth landslide at Bear Hollow Lakes, a private water recreation and residential development, nearly impacted a house. A concrete block barrier was subsequently placed below the landslide in an attempt to protect the house.

Wet years with rapid snowmelt and rain events continue to show Box Elder County's vulnerability to overland flooding, riverine flooding and landslides. Communities that have developed in areas where flooding and landslides damage houses and infrastructure face difficult challenges on how to manage these areas in the future. The 1983 and 2017 flooding and landslide events provide important lessons on where to build safely and how to manage these hazards when they occur. Because these landslides have shown historical movement prior to 2017, they will likely move again in the future.

FLOODING HAZARDS

Flooding is the overflow of water onto lands that are normally dry and is the most commonly experienced natural hazard. Damage from flooding includes inundation of land and property, erosion, deposition of sediment and debris and the force of the water itself, which can damage property and take lives. Historically, flooding is the most prevalent, costly, and destructive (on an annual basis) hazard in Utah. Flooding often occurs outside of Federal Emergency Management Agency (FEMA) mapped flood zones, mainly due to outdated mapping, topographic, building and infrastructure changes made after flood map publication, changes to climate conditions, and the increase in generally impermeable ground surfaces due to urbanization.

Types of Flooding Hazards

River, Lake, or Sheet Flooding

(Covered in the Flooding Hazards section of the state plan.)

Debris Flows and Alluvial Fan Flooding

(Covered in the Landslides, Debris Flow section above.)

Dam and Water Conveyance Structure Failure

(Covered in the Flooding Hazards section of the state plan.)

Seiches

(Covered in the Geologic Hazards, Earthquake Seismic Hazards section of the state plan.)

Tsunamis

(Covered in the Geologic Hazards, Earthquake Seismic Hazards section of the state plan.)

Shallow Groundwater

Shallow groundwater, typically about <10 feet beneath the ground surface, can flood basements and other underground facilities, damage buried utility lines and destabilize excavations.

Problem Soil and Rock Hazards

Problem soils, such as expansive, compressible and collapsible soils can cause extensive damage to structures and foundations. Problem soils may also damage pavements after construction, resulting in high maintenance and replacement costs, along with increased legal and financial liability from pavement separation and gaps causing possible trip hazards. In addition, future maintenance may disrupt business activities, resulting in increased costs or lost revenue. Except for radon gas, no deaths have been reported in Utah from other problem soil and rock hazards, however, they have caused an undetermined, but significant amount of infrastructure damage and economic impact.

Types of Problem Soil and Rock Hazards

Breccia Pipes and Karst

Breccia pipes are rubble-filled vertical tubes that form and project to the surface as overlying strata collapse into buried karst caverns. Karst is a topography formed from the dissolution of soluble rocks such as limestone, dolomite and gypsum. It is characterized by producing ridges, towers, fissures and underground drainage systems with sinkholes and caves. These pipes are often unstable and significant sinkhole and differential settlement may occur above and within them.

Limestone

A hard sedimentary rock formed chiefly by accumulation of organic remains (such as shells or coral), composed mainly of calcium carbonate or dolomite, used as building material and in the making of cement. It yields lime when burned.

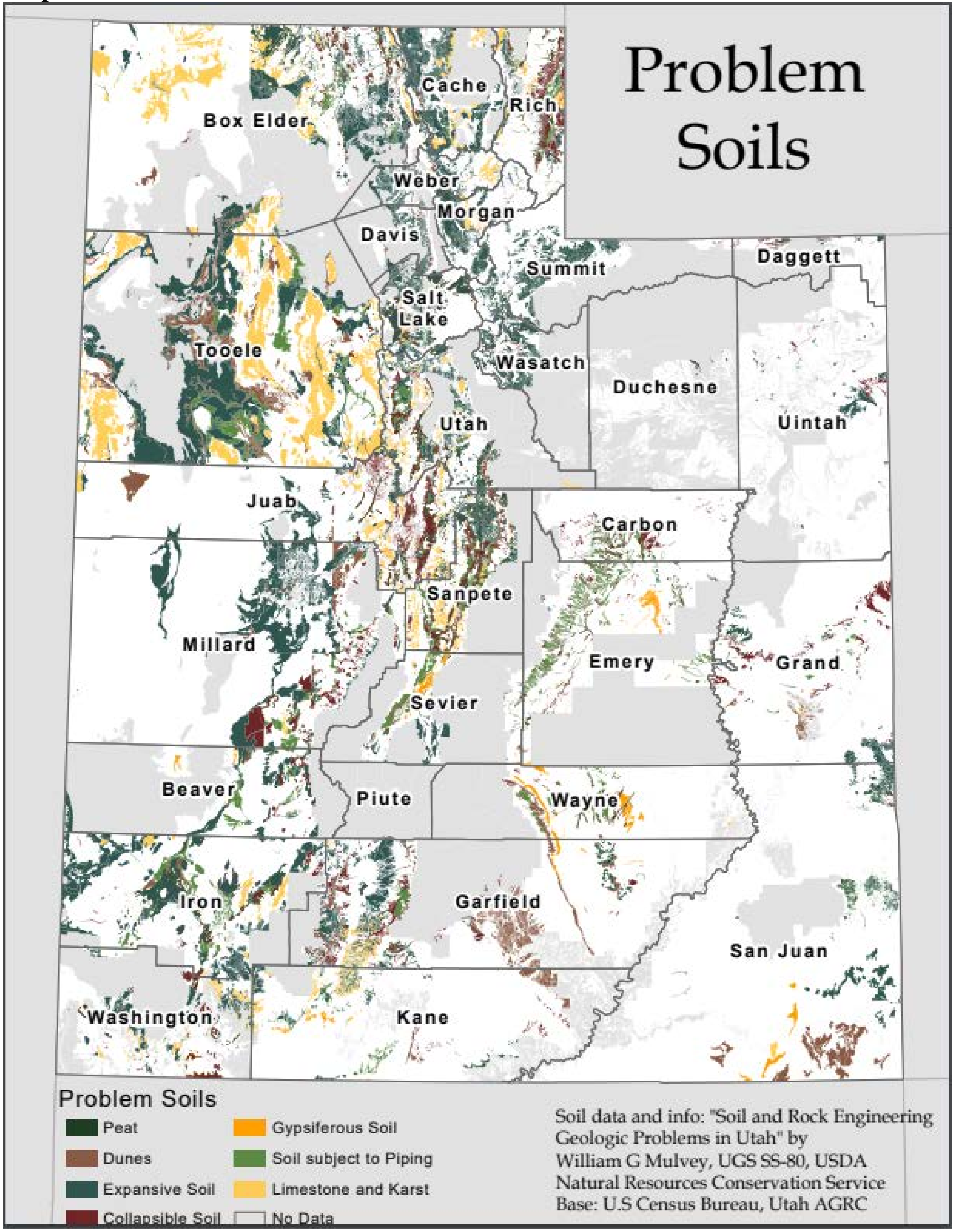
Caliche

Caliche is a calcareous material of secondary origin that typically accumulates through pedogenic processes in the shallow subsurface of soils in arid and semiarid climates and can be very difficult to excavate. The presence of caliche can prevent adequate percolation of septic effluent, leading to individual waste water system failure, difficult in construction excavations and other issues.

Corrosive Soil and Rock

Soil and rock that are corrosive to exposed metals and concrete lead to significant damage to these materials over time. They may cause pipe walls to become thin and weak, leading to failure and for pipe buried near or above surface concrete to decay and lose strength.

Map 7. Utah Problem Soils

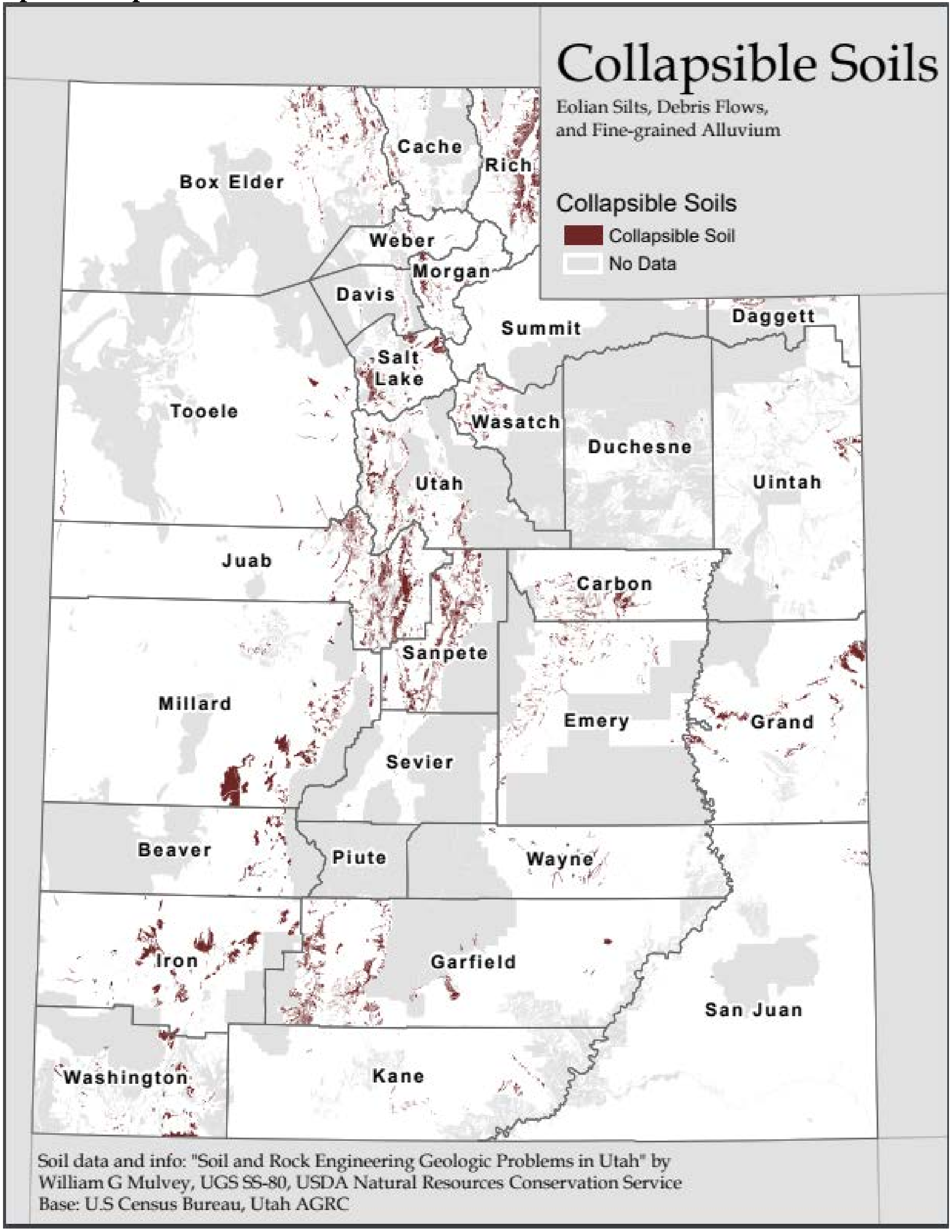


Soil data and info: "Soil and Rock Engineering Geologic Problems in Utah" by William G Mulvey, UGS SS-80, USDA Natural Resources Conservation Service
Base: U.S Census Bureau, Utah AGRC

Map 8. Limestone and Karst Terrain

Soil data and info: "Soil and Rock Engineering Geologic Problems in Utah" by William G Mulvey, UGS SS-80, USDA Natural Resources Conservation Service
Base: U.S Census Bureau, Utah AGRC

Map 9. Collapsible Soils



Soil data and info: "Soil and Rock Engineering Geologic Problems in Utah" by William G Mulvey, UGS SS-80, USDA Natural Resources Conservation Service
Base: U.S Census Bureau, Utah AGRC

Collapsible Soils

Hydrocompactive soils are the most common type of collapsible soil. The term suggests that the introduction or presence of water and the resultant compaction of the soils once they become wet is the driving mechanism. Hydrocompactive soils form in semi-arid to arid climates in the western US in specific depositional environments characterized by low density and moisture contents. The grains in this dry soil are not packed tightly and are held together by clay, silt and soil suction pressure. While strong when dry, with the introduction of water the binding agents quickly break, soften, disperse, or dissolve. This relatively rapid densification of the soil manifests as subsidence or settlement.

Collapsible soils can rapidly settle or collapse the ground damaging man-made structures such as foundations, pavements, concrete slabs, utilities and irrigation lines. This hazard was recognized in the 1890's when previously untouched land was first irrigated. It remains one of the primary geologic hazards that damages home foundations in Utah. Soils that have considerable strength when dry but that significantly settles due to hydro compaction when wetted. Typically associated with young alluvial fans, debris flows and loess. These soils can cause asphalt concrete (AC) and Portland cement concrete (PCC) pavement failure, severe building and infrastructure distress or differential movement and canals and other gravity flow utilities to fail.

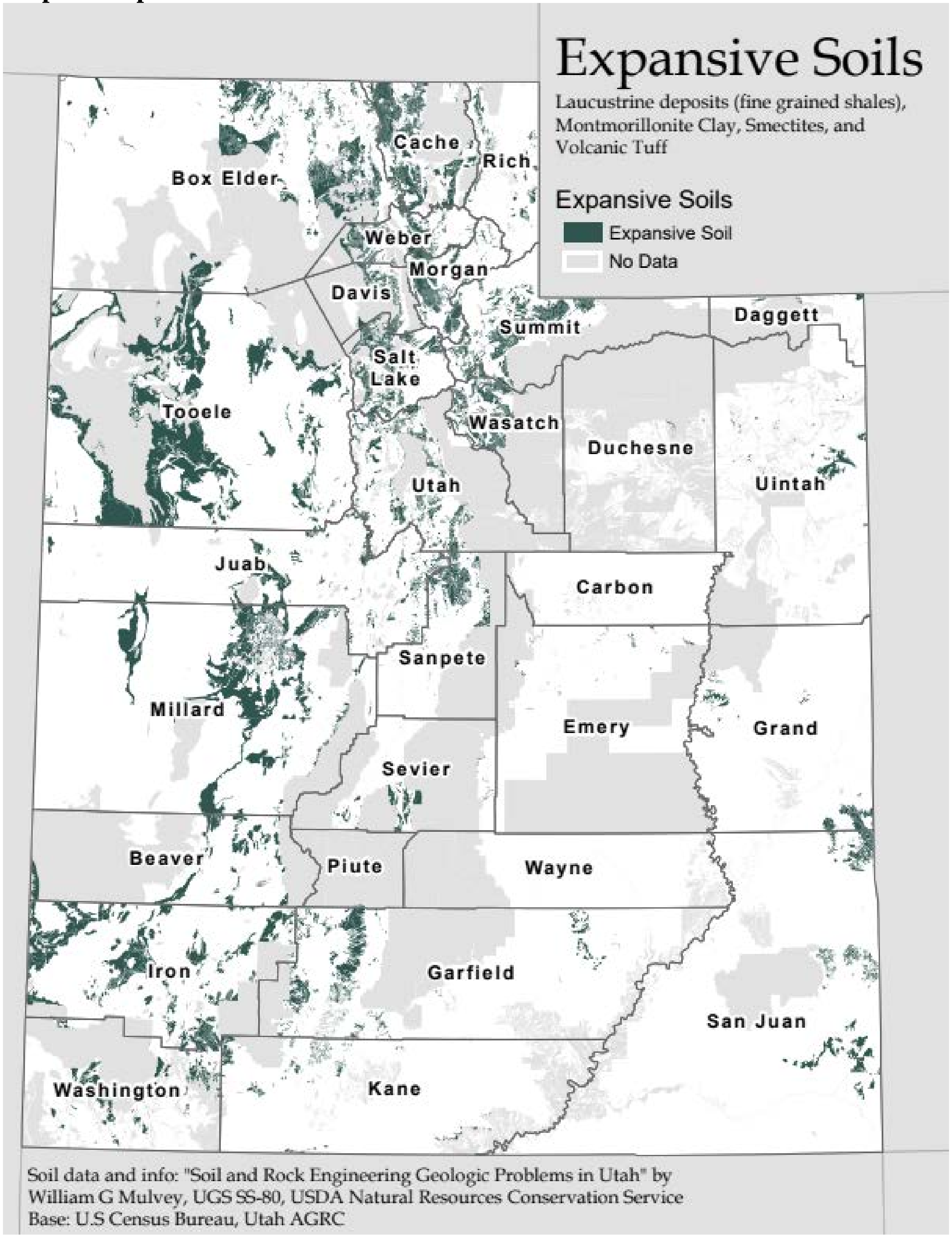
Expansive Soil and Rock

Expansive soils contain minerals such as smectite clays that are capable of absorbing water. When they absorb water, they increase in volume cracking foundations, floors and basement walls**.** Soil and rock that swells when wetted and shrinks when dried is typically, associated with high clay content, particularly sodium-rich clay. These soils can cause AC and PCC pavement failure, severe building and infrastructure distress and differential movement and canals and other gravity flow utilities to fail.

Gypsiferous Soil and Rock

Gypsiferous soils contain sufficient quantities of gypsum (calcium sulphate) to interfere with plant growth. Soils with gypsum are found in regions with ustic, xeric and aridic moisture regimes. Gypsum-bearing soil and rock are subject to dissolution of the gypsum, which causes a loss of internal structure and volume. Where the amount of gypsum is >10 percent, dissolution can result in localized land subsidence and sinkhole formation. Dissolution of gypsum may also lead to foundation collapse problems and may affect roads, dikes, underground utilities and other infrastructure.

Map 10. Expansive Soils



Soil data and info: "Soil and Rock Engineering Geologic Problems in Utah" by William G Mulvey, UGS SS-80, USDA Natural Resources Conservation Service
Base: U.S Census Bureau, Utah AGRC

Map 11. Gypsiferous Soil and Rock

Soil data and info: "Soil and Rock Engineering Geologic Problems in Utah" by William G Mulvey, UGS SS-80, USDA Natural Resources Conservation Service
Base: U.S Census Bureau, Utah AGRC

Land Subsidence and Earth Fissures

Permanent, linear tension cracks in the ground that extend upward from the groundwater table and are a direct result of land subsidence caused by groundwater depletion and mine subsidence. These soils can cause AC and PCC pavement failure, severe building and infrastructure distress and differential movement and canals and other gravity flow utilities to fail.

Piping and Erosion

Subsurface erosion of soil or rock by groundwater flow that forms narrow voids. Piping can remove support of overlying soil and rock, resulting in collapse. This internal erosion of soil can lead to failure of the structure and to sinkhole formation as voids within the soil cause the progressive development of internal erosion by seepage appear downstream as a hole discharging water. Piping and erosion can cause AC and PCC pavement failure, severe building and infrastructure distress and differential movement and canals and other gravity flow utilities to fail.

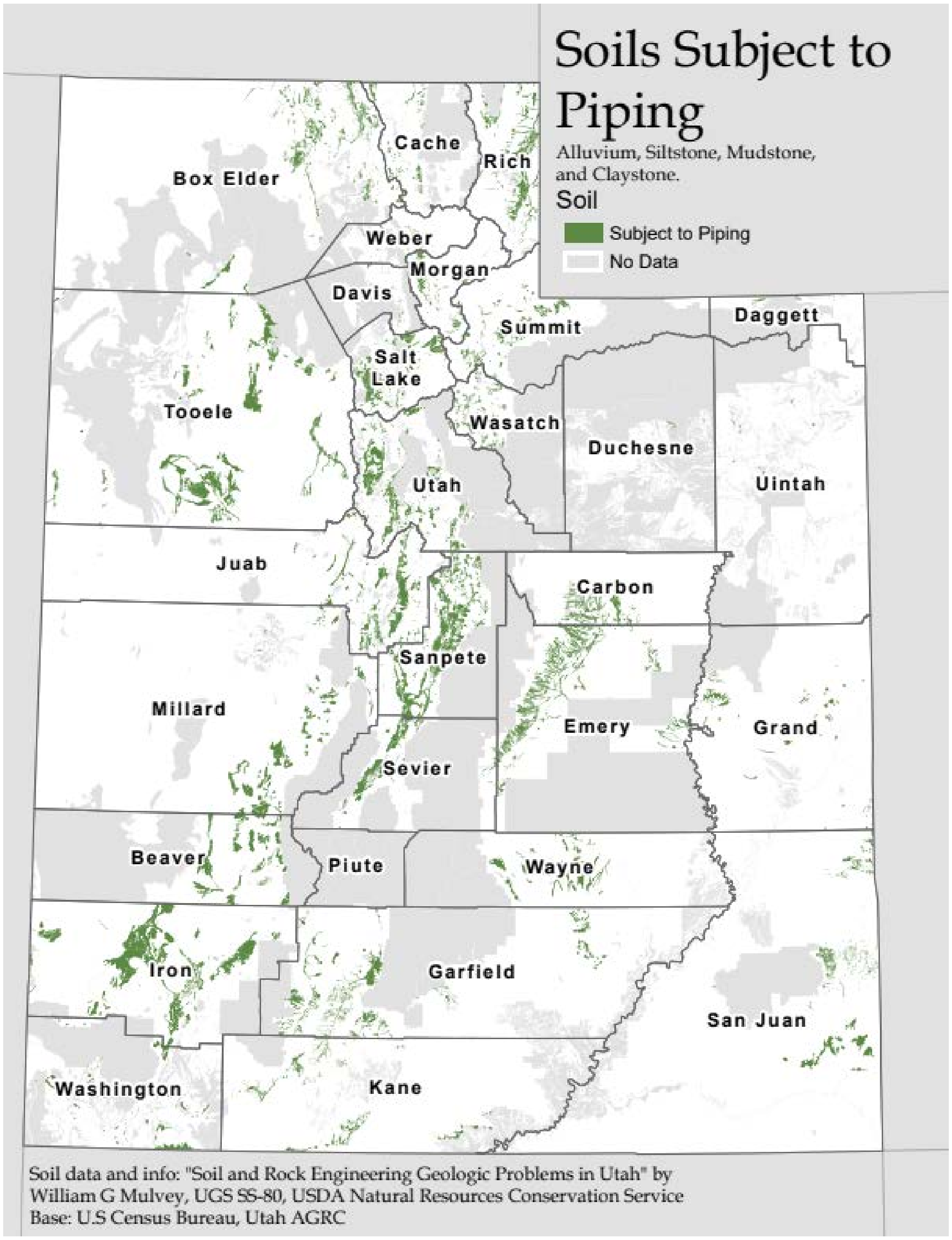
Peat Soil

Partially decayed vegetation or organic material. This soil is problematic because it cannot be easily compacted to serve as a stable foundation to support loads, such as roads or buildings.

Dune

A mound or ridge of sand or other loose sediment formed by the wind, especially on the sea coast or in a desert.

Map 12. Soils Subject to Piping



Soil data and info: "Soil and Rock Engineering Geologic Problems in Utah" by William G Mulvey, UGS SS-80, USDA Natural Resources Conservation Service
Base: U.S Census Bureau, Utah AGRC

Map 13. Peat

Soil data and info: "Soil and Rock Engineering Geologic Problems in Utah" by William G Mulvey, UGS SS-80, USDA Natural Resources Conservation Service
Base: U.S Census Bureau, Utah AGRC

Map 14. Dunes

Soil data and info: "Soil and Rock Engineering Geologic Problems in Utah" by William G Mulvey, UGS SS-80, USDA Natural Resources Conservation Service
Base: U.S Census Bureau, Utah AGRC

Salt Tectonics

Salt formations at depth below the ground surface may deform, causing deformation of cracks at the ground surface. In Utah, salt tectonics-related issues are typically found in the Moab-Spanish Valley area and central Utah east of Interstate 15.

Shallow Bedrock

Bedrock at shallow depths that may be encountered in construction and other excavations and can be very costly when not accounted for in project design.

Wind-Blown Sand

Geologically young, active or partially stabilized, wind-blown or mixed-unit sand deposits characterized by well-sorted, loose, sandy soil texture with few or no fines. Where disturbed, sandy soils may migrate across roads and bury structures, and wind erosion may expose foundations and underground utilities, along with being an inhalation health hazard.

Radon

Radon a radioactive gas that has no smell, taste or color. It comes from the natural decay of uranium that is found in nearly all rock and soil. When geologic conditions are favorable, the potential increases for high indoor levels of radon. Outdoor radon levels never reach dangerous concentrations because air movement scatters radon into the atmosphere. Radon is hazardous in buildings because the gas collects in enclosed spaces. Geologic conditions directly affect indoor radon gas concentrations, however, indoor radon gas concentrations are highly dependent on building construction methods. When geologic and building conditions are favorable, the potential increases for high indoor levels of radon. Four conditions must be present for high indoor-radon levels to occur: (1) structure built on ground that contains sufficient uranium, (2) underlying soil allows easy movement of radon, (3) porous building materials, cracks, or other openings below the ground surface that allow radon from the soil to enter the building, (4) a lower air pressure inside than in the soil around the foundation.

Radon gas is easily dissolved in water and is released into the air during water use and movement. High levels of radon are not common in Utah's public-water supplies, but may be present in well water. There is no safe level of exposure to radon.

Radon decays into radioactive particles that can be trapped in the lungs when inhaled. These particles release small bursts of energy that damage lung tissue and may lead to lung cancer. Radon is the second leading cause of lung cancer in the United States. Between 1973 and 2015, there were approximately 5,630 fatalities in Utah attributable to lung cancer caused by radon gas based on a World Health Organization general estimate that 14% of lung cancer cases are attributable to radon gas. Thousands of fatalities before 1973 from radon gas are likely. To date, lung cancer fatalities caused by radon gas are Utah's most deadly geologic hazard.

Only smoking causes more lung-cancer deaths, and smoking combined with radon is a particularly serious health risk. Chances of getting lung cancer are higher from the combination of smoking and radon than from either source alone. Not everyone who is exposed to radon develops the disease, but the chances increase with increasing levels of radon and exposure time. It may take many years for lung cancer to develop.

In the United States, the U.S. Environmental Protection Agency (EPA) recommends building owners mitigate indoor radon gas concentrations greater than or equal to (≥) 4 picocuries per liter of air (pCi/L). However, the World Health Organization recommends mitigation for indoor concentrations ≥2.7 pCi/L, based on 13 European case-controlled studies of >21,000 participants that showed a significant 8% increase in lung cancer per 2.7 pCi/L radon concentration increase.

There are two ways to test for radon: short-term and long-term testing. The EPA recommends a short-term test first and, if high levels of radon are found (> 4 pCi/L), follow up with either a long-term or a second short-term test. Low-cost, do-it-yourself radon test kits are available both through the mail and in retail outlets, or a contractor licensed by the State of Utah and certified with the National Radon Proficiency Program or National Radon Safety Board can be hired to perform the test.[14]

Short-term testing typically takes from two to 90 days and commonly includes charcoal canisters, alpha track, electric ion chambers, continuous monitors and charcoal liquid scintillation detectors. Because radon levels tend to vary from day to day and season to season, a short-term test is less likely than a long-term test to indicate your year-round average radon level. If results are needed quickly, a short-term test followed by a second short-term test may be used to decide whether to mitigate the home or building.

Long-term testing typically takes more than 90 days and includes an alpha track and electric detectors. A long-term test will result in a reading that is more likely to represent the year-round average radon level than a short-term test.

The EPA suggests that occupants of homes with radon levels above 4 pCi/L take action to reduce indoor-radon concentrations through mitigation. Active air fans and sealed piping are commonly used, along with several other mitigation techniques. Typical costs for adopting radon-resistant construction measures are around $500 in the construction of a new residential home. Active radon mitigation systems installed after the time of construction typically range from $1,200 to $1,700.

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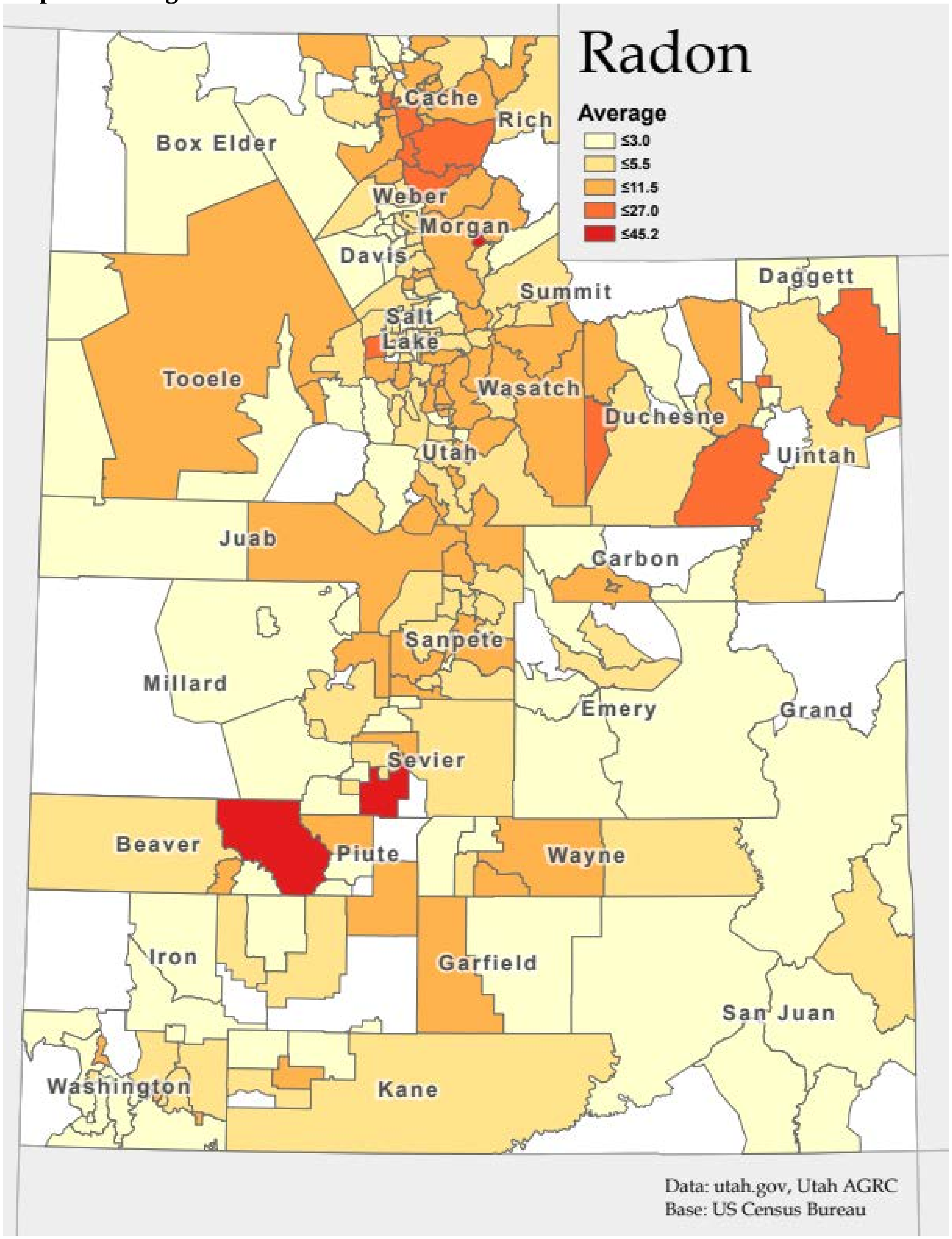
[14] Utah Department of Professional Licensing https://secure.utah.gov/llv/search/index.html, National Radon Proficiency Program http://aarst-nrpp.com, National Radon Safety Board http://www.nrsb.org/

Utah's governor designates a week in January annually as Radon Action Week to increase awareness about the problem and encourage testing. The Utah Department of Health provided funding to the Utah Department of Environmental Quality (DEQ) establishing a program in 2017 to test for radon gas in Utah elementary through high schools. To date, all tested schools have come in below the EPA acceptable level of indoor radon 4 pCi/L. If future Utah schools are identified with a higher than acceptable radon level they will need to mitigate the problem with the assistance of a certified radon mitigator to install a pipe and fan system redirecting the radon outside of the building into the open air where it disperses and is harmless.

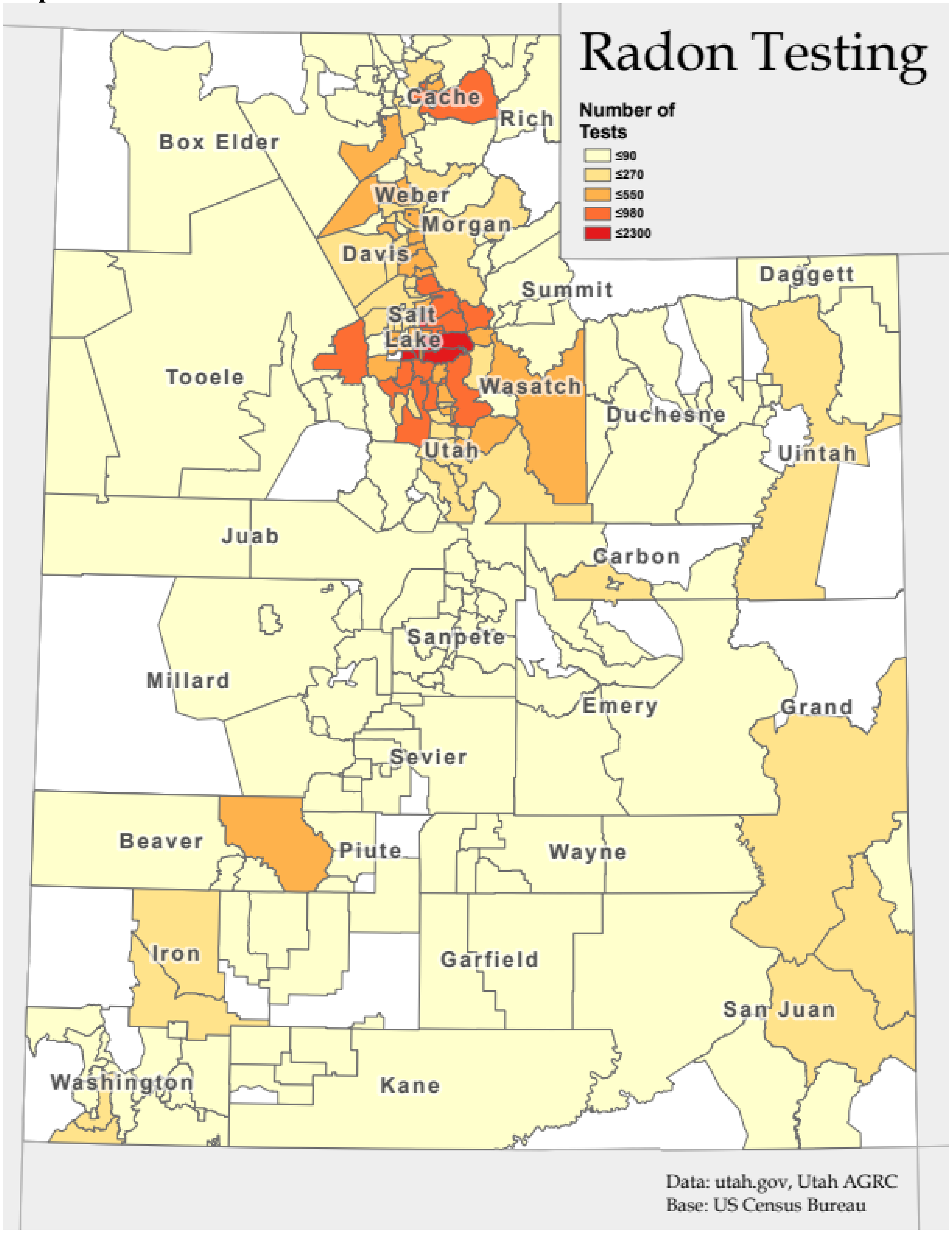
Davis County has also taken the initiative on radon mitigation voluntarily testing all of their schools and constructing their new school buildings with Radon Resistant New Construction (RRNC). This process involves building a radon mitigation system during the initial construction of the school, which is cheaper than adding a radon fan later and prevents children and staff from experiencing any radon exposure.

Map 15. Average Radon



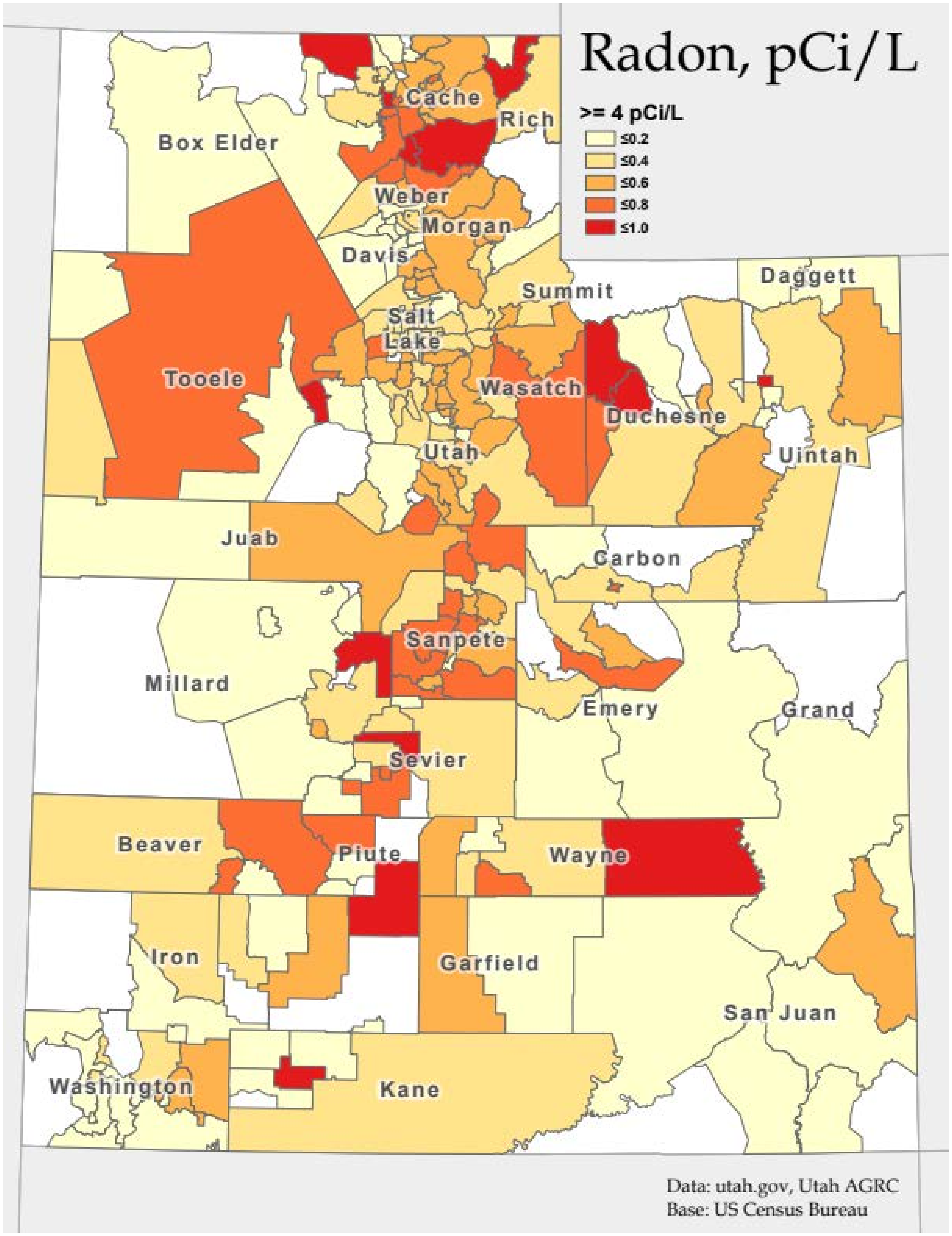
Data: utah.gov, Utah AGRC
Base: US Census Bureau

Map 16. Radon Number of Tests



Data: utah.gov, Utah AGRC
Base: US Census Bureau

Map 17. Radon, pCi

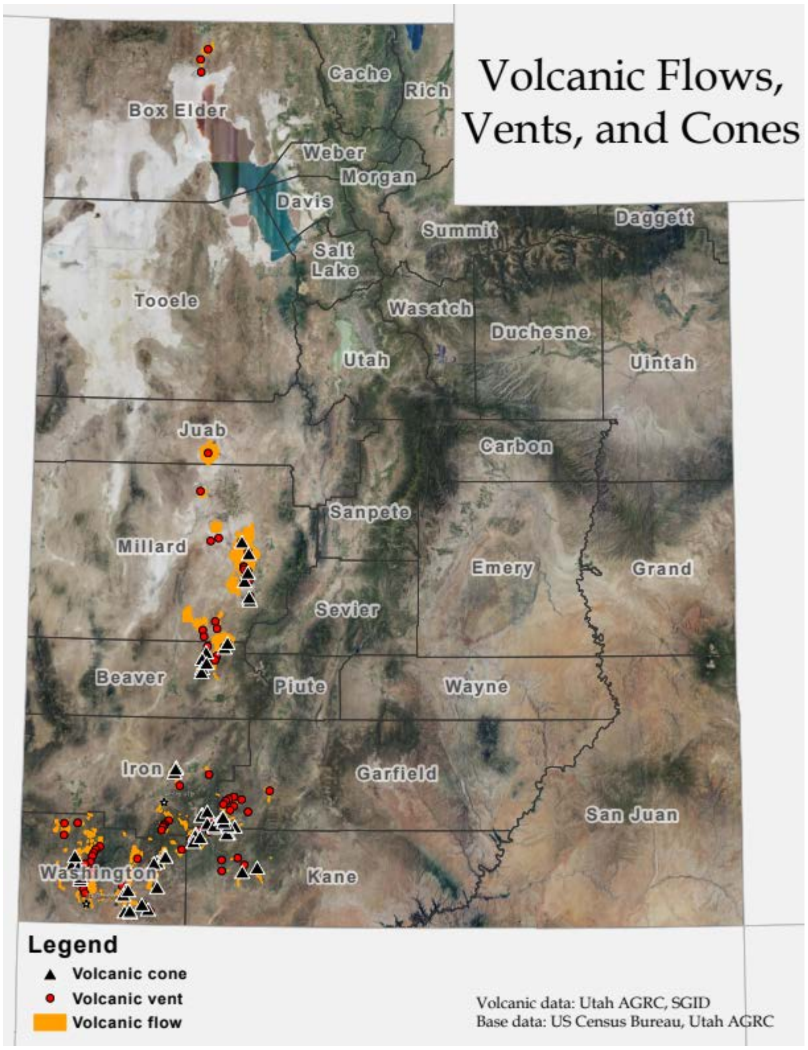


Data: utah.gov, Utah AGRC
Base: US Census Bureau

Volcanic Hazards

Volcanic hazards are typically those associated with active volcanoes and include volcanic eruptions of lava, ash, steam and pyroclastics, lava and pyroclastic flows, lahars (volcanic debris flows), glacier outburst floods, rock, debris and ice avalanches, lateral blasts, tsunamis and dome growth or collapse. However, it is rare that all these hazards exist at a single volcano. While Utah does not have any active volcanoes, several basalt flows in the West Desert area are only several hundred years old and geologically young. In addition, eruptions of volcanoes in the western United States, including the Yellowstone caldera, could result in volcanic ash clouds and significant deposition in Utah, causing widespread damage.

Map 18. Volcanic Flows Vents and Cones



Types of Volcanic Hazards

Volcanoes

Volcanoes are vents opening at the Earth’s crust through which magma (molten rock) and associated gases erupt. Utah contains the three main types of volcanoes: stratovolcanoes, shield volcanoes and cinder cones.

Figure 2. Three Main Types of Volcanoes

THREE MAIN TYPES OF VOLCANOES*

The three main types of volcanoes differ in shape, size, and make-up; the differences partly result from the different types of eruptions.

VOLCANO TYPE	VOLCANO SHAPE	VOLCANO SIZE	VOLCANO MATERIALS	ERUPTION TYPE	UTAH EXAMPLE
Cinder Cone	Steep conical hill with straight sides	Small less than 300m high	cinders	Explosive	Diamond Cinder Cone, Washington County
Shield Volcano	Very gentle slopes; convex upward (shaped like a warrior’s shield)	Large over 10s of kms across	fluid lava flows (basalt)	Quiet	Cedar Hill, Box Elder County
Stratovolcano	Gentle lower slopes, but steep upper slopes; concave upward	Large 1-10 km in diameter	numerous layers of lava and pyroclastics	Explosive	Mount Belknap, Tushar Mountains, and Monroe Peak, Sevier Plateau

Volcanic Eruption

An eruption of molten rock from within the earth may be accompanied by lava, ash, steam and pyroclastics. Eruptions can be violently explosive, such as the 1980 Mount St. Helens eruption, relatively benign as some Hawaiian volcanoes with slow moving lava flows or somewhere in between.

Lava Flows

A flow of molten rock on the earth's surface flowing out of a volcano.

Airborne Volcanic Ash

During a volcanic eruption, ejection of ash and sharp shards of volcanic glass and fragments of rock pulverized by the explosive nature of an eruption are common forming ash clouds that can travel far distances from the volcano, depending on weather and wind conditions. These ash clouds are very dangerous to aircraft, often resulting in engine failure due to the abrasive nature of volcanic ash. In addition, as the clouds move away from the erupting volcano, ash is deposited on the ground surface, where winds may make visibility near-zero. It takes less than ¼-inch of ash on the ground to create significant impacts, such as engine and machinery failure, short-circuiting of outdoor electrical circuits, inhalation and other health hazards, near to complete stoppage of transportation systems, damage to water supplies, etc.

Stratovolcanoes

Stratovolcanoes erupted in western Utah between about 40 to 25 million years ago. At this time, Utah was closer to a continental-oceanic plate boundary where an oceanic plate was subducting underneath the North American continental plate[15]. Stratovolcanoes are found at these types of plate boundaries. Today's active stratovolcanoes include those in the Cascade Range in Washington, Oregon, and California where an oceanic plate (Juan de Fuca) is subducting underneath the North American continental plate. Two examples of Utah's stratovolcanoes are Mount Belknap in the Tushar Mountains and Monroe Peak on the Sevier Plateau. Because these volcanoes are old and have been extensively eroded, it is difficult to distinguish the original volcano shapes.

Shield Volcanoes

Shield volcanoes and cinder cones started to erupt about 12 million years ago after plate motions and resulting crustal forces changed. Compressional forces had eased, and the crust started to stretch between the Wasatch Range in Utah and the Sierra Nevada Range in California. This extension created splintered zones in the Earth's crust where magma rose to the surface creating shield volcanoes and cinder cones. The most recent volcanic activity in Utah occurred about 600 years ago in the Black Rock Desert (Millard County).

Magma

Magna is molten rock beneath the surface of the Earth.

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[15] (Farallon)

Lava

Lava is magma that has reached the surface.

Cinders

Cinders are lava fragments about 1 centimeter in diameter.

Pyroclastics “fire fragments”

Pyroclastics are ash, cinders, angular blocks, and rounded bombs (block and bomb fragments can be over 1 meter in diameter).

Explosive eruptions

Volcano ejecting lava and pyroclastics.

Quiet eruptions

Fluid lava flows out of a volcano’s vent.

Fault

A fault is a crack in the Earth's crust typically associated with or forming the boundaries between Earth's tectonic plates. In an active fault, the pieces of the Earth's crust along a fault move over time. The moving rocks can cause earthquakes.

Fissure

A fissure is a long and narrow crack or opening in the earth.

8.2 Assessment of Local Geological Hazard Vulnerability and Potential Losses

An analysis was performed to determine the square mileage of landslide susceptibility for each county using GIS data. The counties with highest square mileage of landslide susceptibility in Utah are San Juan, Kane, Grand, Uintah, and Millard counties. However, these counties are not among the most populous counties. Washington and Utah counties, have the 6th and 7th highest square mileage to landslide susceptibility and are among the most populous counties in the state.

Table 2. Area of square miles per county with high or moderate landslide risk

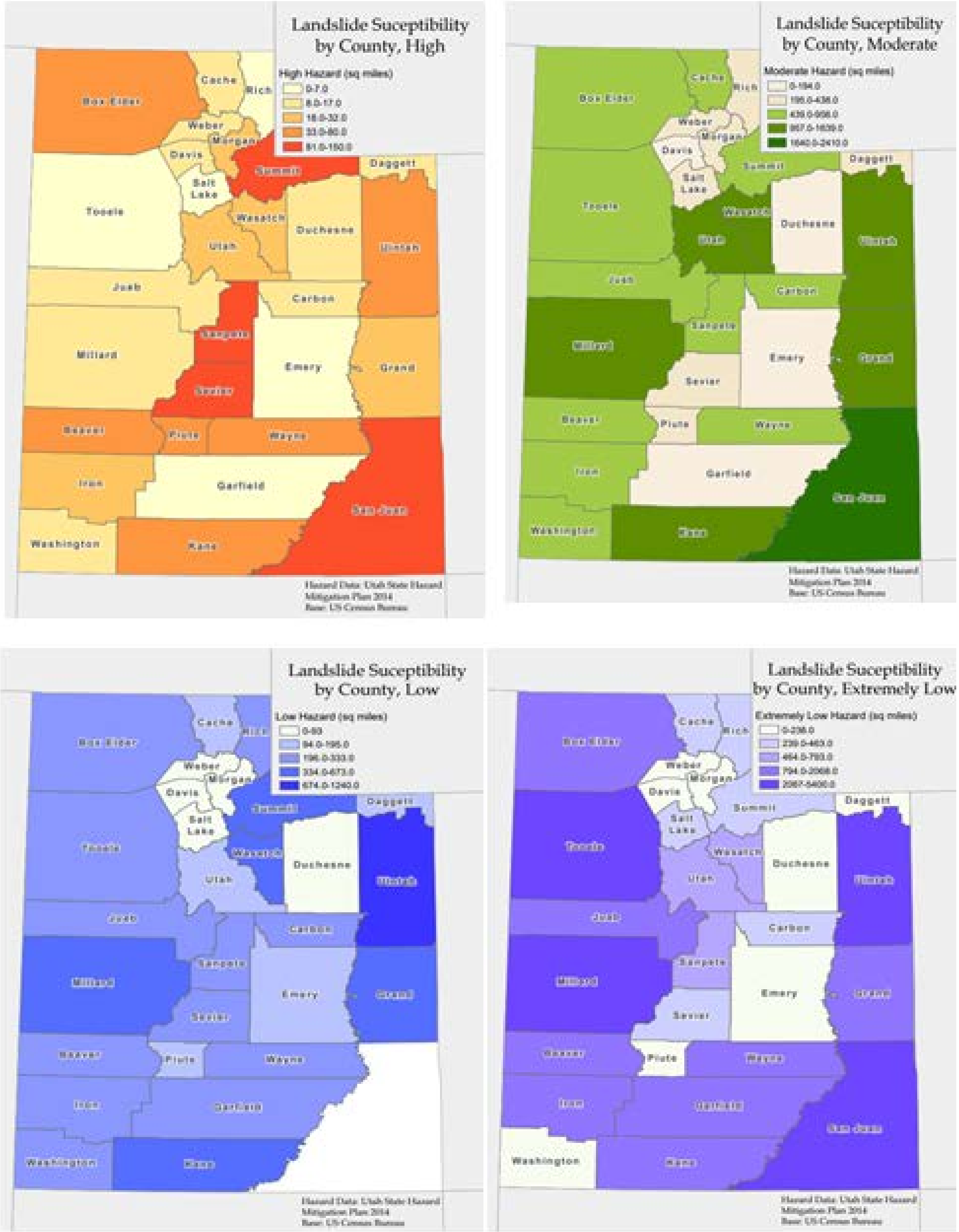
County	Areas within High or Moderate Landslide Susceptibility Areas (square miles)
San Juan	2512.3
Kane	1680.5
Grand	1537.9
Uintah	1367.1
Millard	1187.8
Washington	1108
Utah	1076.7
Summit	1035.8
Box Elder	1010.8
Tooele	938.3
Carbon	818.4
Juab	803.6
Wayne	785.4
Sanpete	783.6
Iron	758.7
Wasatch	717.91
Beaver	625.6
Sevier	587.4
Cache	563.5
Morgan	449.3
Piute	361.7
Salt Lake	321.6
Daggett	312.2
Rich	263.9
Weber	261.8
Garfield	197.5
Emery	128.02
Duchesne	104.6
Davis	104
Total	**23,815.66**

The analysis on landslide susceptibility also broke down the hazard by different hazard categories – high, moderate, low, and extremely low. The counties with the highest square mileage to the category of high hazard landslide susceptibility include Sevier, San Juan, Sanpete, Summit, and Piute counties.

Table 3. Summary of Landslide Susceptibility per County by Hazard Category

County Name	High Hazard (square miles)	Moderate Hazard (square miles)	Low Hazard (square miles)	Extremely Low Hazard (square miles)
Beaver	46.6	579	236.1	1365.4
Box Elder	46.6	579	236.1	1365.4
Cache	10.8	552.7	161.2	365.3
Carbon	7.1	811.3	219.4	407.3
Daggett	8.7	303.5	165.5	195.7
Davis	15.4	89	14.6	16.9
Duchesne	15.4	89.2	14.6	167.6
Emery	2.02	126	143.1	175.3
Garfield	3.7	193.8	223.5	1763.1
Grand	17.2	1520.7	547.9	1508.6
Iron	20.5	738.2	333	1906.5
Juab	15.2	788.4	211.4	1999.5
Kane	42	1638.5	672.9	1530.9
Millard	13.1	1174.7	396.9	4524.1
Morgan	25.7	423.6	92.3	46.7
Piute	65.9	295.8	121.6	211.7
Rich	1.2	262.7	227.3	449.4
Salt Lake	1.63	320	25	373.9
San Juan	102.6	2409.7	1287.8	3765.9
Sanpete	100.9	682.7	254.8	463.1
Sevier	149.7	437.7	317.2	458.5
Summit	80.1	955.7	417.9	348.1
Tooele	1.3	937	233.2	5396.4
Uintah	32.4	1334.7	906.2	2068.1
Utah	21.1	1055.6	195	591.3
Wasatch	9.51	708.4	247.3	160.1
Washington	28.1	1079.9	423.2	792.9
Wayne	48.7	736.7	323.6	1239.9
Weber	15	246.8	61.9	237.2
Total	**948.16**	**21071**	**8710.5**	**33894.8**

Map 19. Landslide Susceptibility by County

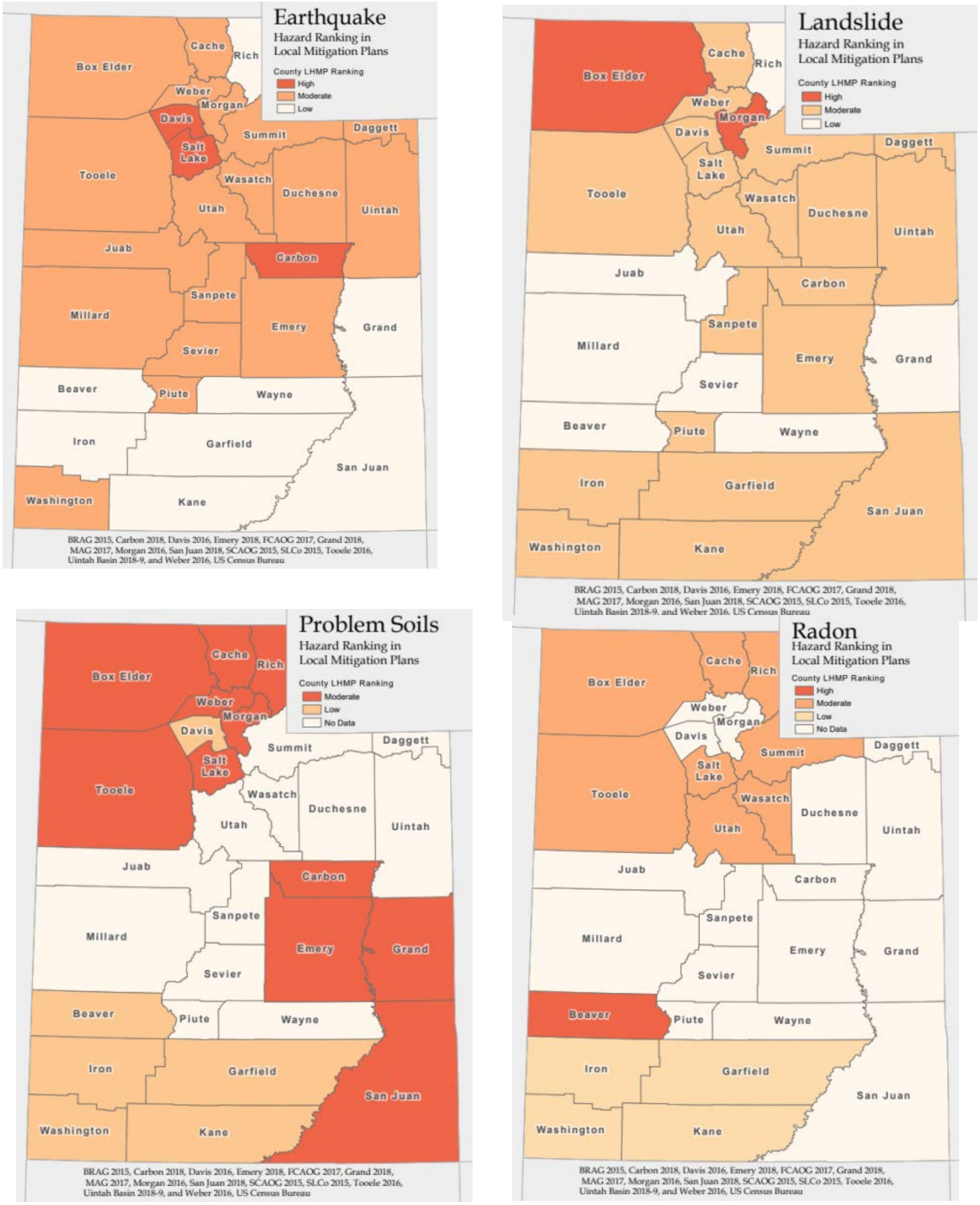


Maps were also created that show the hazard ranking for earthquake, landslide, problems soils, and radon for each county as reported in the LHMPs (see Map 4). The hazard ranking is calculated from a combination of severity (categorized from 0-4) and frequency (categorized from 0-4). This allows for a ranking from 0-8 when combined. The reporting in the LHMPs does not represent actual risk, but perceived risk.

Based on the reporting in LHMPs, the majority of the state has moderate ranking for earthquake, with Carbon, Davis, and Salt Lake counties reported the highest risk. The lower portion of the state (except Washington County) reported low earthquake risk. Most of the counties reported as being at moderate risk to landslides, with Box Elder and Morgan counties reported the highest risk. The Six County region and Grand County reported the lowest risk to landslides.

For problem soils, the northwestern portion of the state and the southeastern portion of the state, reported to be at the most risk in their respective county LHMPs. Many of the counties did not report on problem soils. Reporting on radon in the LHMPs was sporadic, with Beaver County reporting as being at the highest risk.

Map 20. Geologic Hazards Rankings from LHMPs



BRAG 2015, Carbon 2018, Davis 2016, Emery 2018, FCAOG 2017, Grand 2018, MAG 2017, Morgan 2016, San Juan 2018, SCAOG 2015, SLCo 2015, Tooele 2016, Uintah Basin 2018-9, and Weber 2016, US Census Bureau

BRAG 2015, Carbon 2018, Davis 2016, Emery 2018, FCAOG 2017, Grand 2018, MAG 2017, Morgan 2016, San Juan 2018, SCAOG 2015, SLCo 2015, Tooele 2016, Uintah Basin 2018-9, and Weber 2016, US Census Bureau

BRAG 2015, Carbon 2018, Davis 2016, Emery 2018, FCAOG 2017, Grand 2018, MAG 2017, Morgan 2016, San Juan 2018, SCAOG 2015, SLCo 2015, Tooele 2016, Uintah Basin 2018-9, and Weber 2016, US Census Bureau

BRAG 2015, Carbon 2018, Davis 2016, Emery 2018, FCAOG 2017, Grand 2018, MAG 2017, Morgan 2016, San Juan 2018, SCAOG 2015, SLCo 2015, Tooele 2016, Uintah Basin 2018-9, and Weber 2016, US Census Bureau

For the SHMP 2019 update, the SHMPC looked at the county LHMPs to gather data on the vulnerability and losses of people, residential units, commercial units, and critical facilities for each county that reported such data. Only 12 counties reported on such data related to earthquakes in their LHMPs. Because not all counties reported on such data and even the counties that did report, did not report on everything examined here, the actual numbers and values are underrepresented in this analysis. The counties that reported the most people vulnerable to earthquakes were Box Elder (27,820), Cache (9,222), and Tooele (4,549). There were 252,985 residential units, for a total value of over $291 million dollars, and 10,596 commercial units, for a total value of around $3 billion dollars that was reported to be vulnerable to earthquake hazards. Over 1400 critical facilities were also listed as being at risk to earthquake hazards. These numbers underrepresent the actual values for the whole state.

Table 4. Earthquake Risk Figures as Reported in LHMPs

Earthquake

County	People	Residential Units		Commercial Units		Critical Facilities
		Units	Value	Units	Value	
Box Elder	27,820	8888	$1,545,521,701	1100	$759,298,040	340
Cache	9222	2710	$751,026,178	247	$176,557,372	674
Carbon	99	3296	$319,740,000	512	$60,300,000	53
Davis		41310		954		
Emery	56	2475	$22,550,000	284	$10,230,000	89
Grand		1048	$14,720,000	88	$5,320,000	1
Morgan		3274		45		
Rich	424	130	$16,972,688	4	$717,171	11
Salt Lake		157,705		5199		
San Juan		1309	$15,680,000	79	$4,380,000	
Tooele	4549	1383	$275,924,448	123	$136,379,438	50
Weber		29457		1961		216

Only 9 counties reported on such data related to problem soils in their LHMPs. Because not all counties reported on such data and even the counties that did report, did not report on everything examined here, the actual numbers and values are underrepresented in this analysis. The counties that reported the most people vulnerable to landslides were Salt Lake (90,588), Davis (41,544), and Weber (40,531). There were 72,221 residential units, for a total value of over $13.6 billion dollars, and 1848 commercial units, for a total value of over $2.6 billion dollars that was reported to be vulnerable to landslides. Over 500 critical facilities were also listed as being at risk to landslides. These numbers underrepresent the actual values for the whole state.

Table 5. Landslide Risk Figures as Reported in LHMPs

Landslide

County	People	Residential Units		Commercial Units		Critical Facilities
		Units	Value	Units	Value	
Beaver		171	$18,066,873			
Box Elder	3724	1189	$237,702,202	112	$32,450,429	74
Cache	9673	2986	$805,930,668	196	$53,623,845	87
Carbon	127	97	$7,627,789			
Davis	41,544	11476	$2,232,460,200	363	$44,750,388	
Emery						17
Garfield		207	$26,237,726	10	$1,091,367	
Grand	147	102	$12,801,000			8
Iron		1831	$282,353,651	38	$20,362,484	
Kane		1351	$135,336,912	54	$78,798,611	
Morgan	4,016	1323	$268,569,000	33	$8,272,812	
Rich	2520	773	$133,465,568	10	$5,447,919	260
Salt Lake	90,588	29,894	$6,058,717,500	488	$146,578,278	
Tooele	492	151	$37,182,771	17	$18,286,368	51
Weber	40,531	13916	$2,023,386,400	125	$1,903,607,575	4
Washington		6754	$1,343,669,300	402	$316,394,600	

Table 6. Problem Soils Risk Figures as Reported in LHMPs

Problem Soils

County	People	Residential Units		Commercial Units		Critical Facilities
		Units	Value	Units	Value	
Carbon						57
Garfield		285	$29,195,700	27	$6,035,685	
Iron		6380	$835,741,695	810	$312,098,537	
Kane		175	$13,997,003	15	$2,175,190	
Morgan	2,875	964	$195,692,000	33	$8,272,812	
Rich	664	204	$37,399,143	5	$3,471,278	
Tooele	23,121	7225	$1,198,967,090	184	$373,017,483	87
Weber						7
Washington		7707	$1,258,875,905	176	$182,409,965	

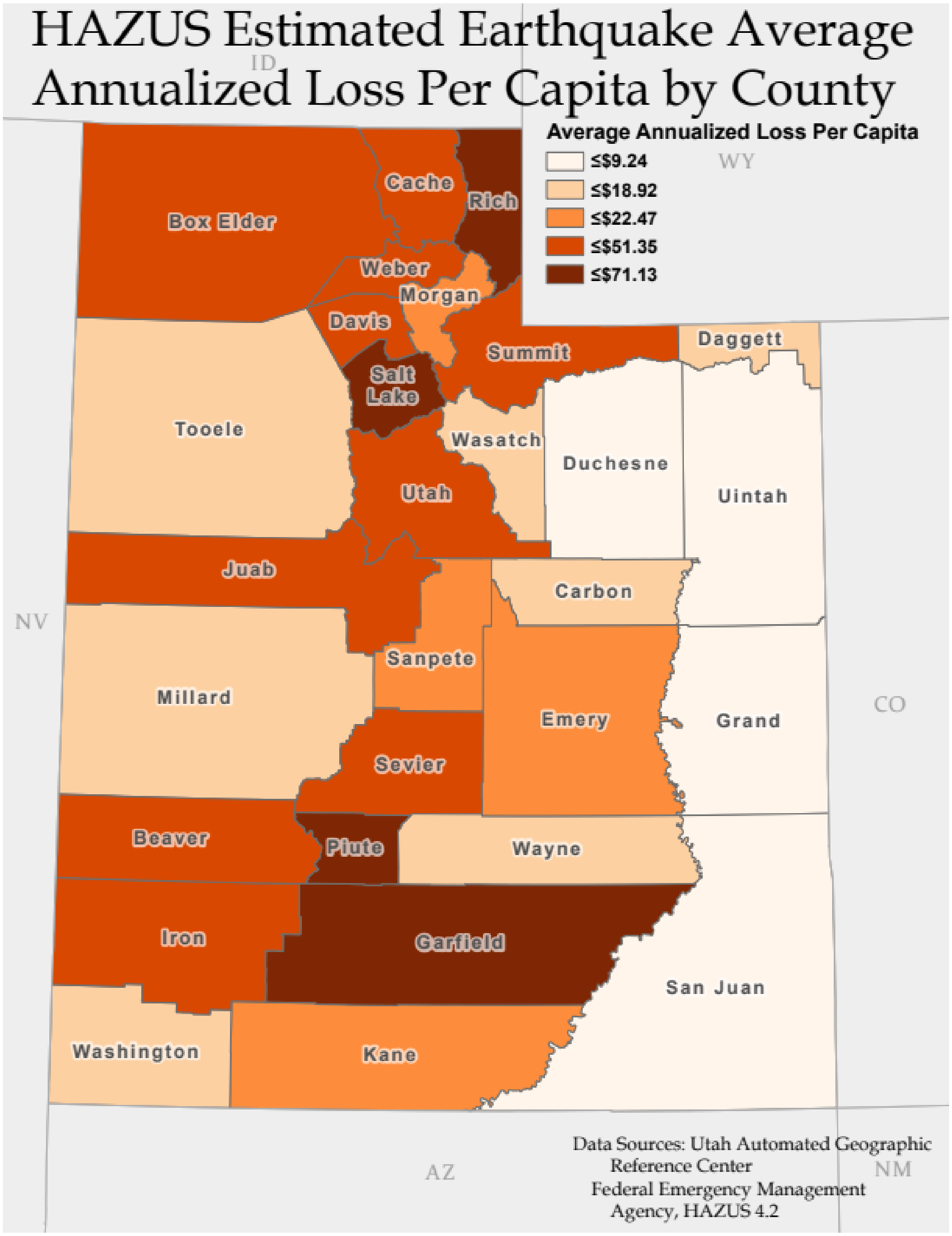
Only 9 counties reported on such data related to problem soils in their LHMPs. Because not all counties reported on such data and even the counties that did report, did not report on everything examined here, the actual numbers and values are underrepresented in this analysis. Three counties reported people being vulnerable to problem soils. These were Tooele (23,121), Morgan (9,222), and Rich (664). There were 22,940 residential units, for a total value of over $3.5 billion dollars, and 1250 commercial units, for a total value of over $887 million dollars that was reported to be vulnerable to problem soils. Over 150 critical facilities were also listed as being at risk to earthquake hazards. These numbers underrepresent the actual values for the whole state.

HAZUS Earthquake Analysis

The Utah Division of Emergency Management (DEM) created a statewide earthquake HAZUS study region to perform an average annualized loss (AAL) analysis. An AAL analysis allows DEM to examine losses across the state both in terms of total expected loss per year as well as per capita loss per year.

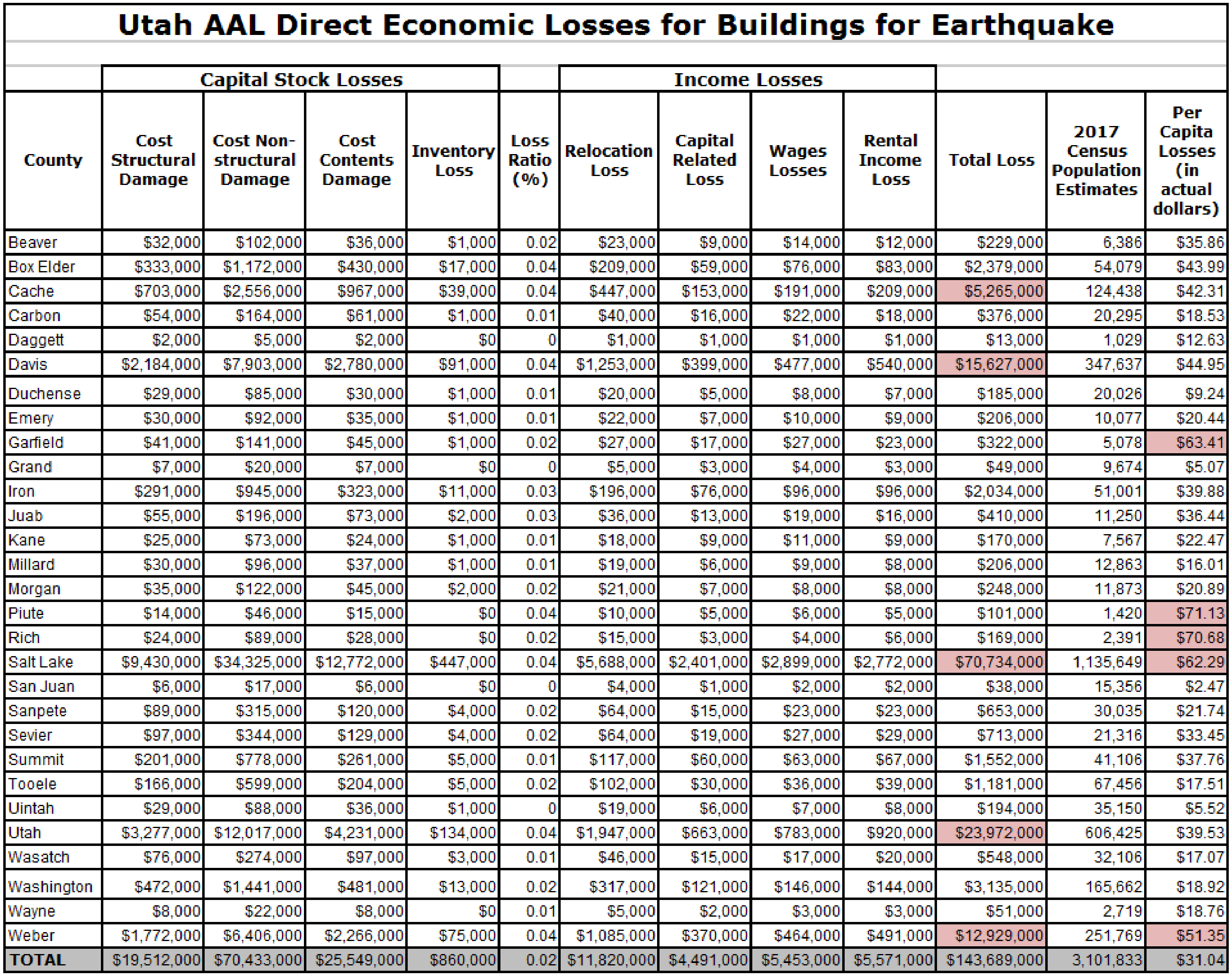
One of the outputs from HAZUS is an AAL analysis related to Direct Economic Losses for Buildings. These results are shown in the following table. There are eight counties where HAZUS estimates more than $2,000,000 in annual direct economic losses: Box Elder, Cache, Davis, Iron, Salt Lake, Sanpete, Utah, Washington, and Weber counties. Ten of the 29 counties in Utah have HAZUS estimates of more than $1,000,000 in annual direct economic losses. As part of our AAL analysis, we calculated the per capita direct economic losses by dividing the total direct economic losses by the 2017 Census population estimates for each county. Salt Lake County had the highest total direct economic losses ($70,734,000). Piute County had the highest per capita losses ($71.13). There are five counties where HAZUS estimates more than $50 in per capita losses from earthquakes.

Map 21. HAZUS Estimated Earthquake Average Annualized Loss Per Capita by County



Data Sources: Utah Automated Geographic Reference Center
Federal Emergency Management Agency, HAZUS 4.2

Table 7. HAZUS Earthquake Results



Utah AAL Direct Economic Losses for Buildings for Earthquake

	Capital Stock Losses					Income Losses						
County	Cost Structural Damage	Cost Non-structural Damage	Cost Contents Damage	Inventory Loss	Loss Ratio (%)	Relocation Loss	Capital Related Loss	Wages Losses	Rental Income Loss	Total Loss	2017 Census Population Estimates	Per Capita Losses (in actual dollars)
Beaver	$32,000	$102,000	$36,000	$1,000	0.02	$23,000	$9,000	$14,000	$12,000	$229,000	6,386	$35.86
Box Elder	$333,000	$1,172,000	$430,000	$17,000	0.04	$209,000	$59,000	$76,000	$83,000	$2,379,000	54,079	$43.99
Cache	$703,000	$2,556,000	$967,000	$39,000	0.04	$447,000	$153,000	$191,000	$209,000	$5,265,000	124,438	$42.31
Carbon	$54,000	$164,000	$61,000	$1,000	0.01	$40,000	$16,000	$22,000	$18,000	$376,000	20,295	$18.53
Daggett	$2,000	$5,000	$2,000	$0	0	$1,000	$1,000	$1,000	$1,000	$13,000	1,029	$12.63
Davis	$2,184,000	$7,903,000	$2,780,000	$91,000	0.04	$1,253,000	$399,000	$477,000	$540,000	$15,627,000	347,637	$44.95
Duchense	$29,000	$85,000	$30,000	$1,000	0.01	$20,000	$5,000	$8,000	$7,000	$185,000	20,026	$9.24
Emery	$30,000	$92,000	$35,000	$1,000	0.01	$22,000	$7,000	$10,000	$9,000	$206,000	10,077	$20.44
Garfield	$41,000	$141,000	$45,000	$1,000	0.02	$27,000	$17,000	$27,000	$23,000	$322,000	5,078	$63.41
Grand	$7,000	$20,000	$7,000	$0	0	$5,000	$3,000	$4,000	$3,000	$49,000	9,674	$5.07
Iron	$291,000	$945,000	$323,000	$11,000	0.03	$196,000	$76,000	$96,000	$96,000	$2,034,000	51,001	$39.88
Juab	$55,000	$196,000	$73,000	$2,000	0.03	$36,000	$13,000	$19,000	$16,000	$410,000	11,250	$36.44
Kane	$25,000	$73,000	$24,000	$1,000	0.01	$18,000	$9,000	$11,000	$9,000	$170,000	7,567	$22.47
Millard	$30,000	$96,000	$37,000	$1,000	0.01	$19,000	$6,000	$9,000	$8,000	$206,000	12,863	$16.01
Morgan	$35,000	$122,000	$45,000	$2,000	0.02	$21,000	$7,000	$8,000	$8,000	$248,000	11,873	$20.89
Piute	$14,000	$46,000	$15,000	$0	0.04	$10,000	$5,000	$6,000	$5,000	$101,000	1,420	$71.13
Rich	$24,000	$89,000	$28,000	$0	0.02	$15,000	$3,000	$4,000	$6,000	$169,000	2,391	$70.68
Salt Lake	$9,430,000	$34,325,000	$12,772,000	$447,000	0.04	$5,688,000	$2,401,000	$2,899,000	$2,772,000	$70,734,000	1,135,649	$62.29
San Juan	$6,000	$17,000	$6,000	$0	0	$4,000	$1,000	$2,000	$2,000	$38,000	15,356	$2.47
Sanpete	$89,000	$315,000	$120,000	$4,000	0.02	$64,000	$15,000	$23,000	$23,000	$653,000	30,035	$21.74
Sevier	$97,000	$344,000	$129,000	$4,000	0.02	$64,000	$19,000	$27,000	$29,000	$713,000	21,316	$33.45
Summit	$201,000	$778,000	$261,000	$5,000	0.01	$117,000	$60,000	$63,000	$67,000	$1,552,000	41,106	$37.76
Tooele	$166,000	$599,000	$204,000	$5,000	0.02	$102,000	$30,000	$36,000	$39,000	$1,181,000	67,456	$17.51
Uintah	$29,000	$88,000	$36,000	$1,000	0	$19,000	$6,000	$7,000	$8,000	$194,000	35,150	$5.52
Utah	$3,277,000	$12,017,000	$4,231,000	$134,000	0.04	$1,947,000	$663,000	$783,000	$920,000	$23,972,000	606,425	$39.53
Wasatch	$76,000	$274,000	$97,000	$3,000	0.01	$46,000	$15,000	$17,000	$20,000	$548,000	32,106	$17.07
Washington	$472,000	$1,441,000	$481,000	$13,000	0.02	$317,000	$121,000	$146,000	$144,000	$3,135,000	165,662	$18.92
Wayne	$8,000	$22,000	$8,000	$0	0.01	$5,000	$2,000	$3,000	$3,000	$51,000	2,719	$18.76
Weber	$1,772,000	$6,406,000	$2,266,000	$75,000	0.04	$1,085,000	$370,000	$464,000	$491,000	$12,929,000	251,769	$51.35
TOTAL	$19,512,000	$70,433,000	$25,549,000	$860,000	0.02	$11,820,000	$4,491,000	$5,453,000	$5,571,000	$143,689,000	3,101,833	$31.04

Climate Change Impacts

Climate change will alter the risk of landslides in Utah. The amount, timing and type of precipitation in Utah will change throughout the twenty-first century. In general, projections of precipitation suggest that by 2100, northern Utah will receive more precipitation and southern Utah will receive less precipitation compared to historical averages. More importantly to landslide risk, the timing and type of precipitation is likely to change. A higher risk of landslides exists when soils are saturated with water. Warmer future winter temperatures will create a scenario where landslides may be more likely. Warmer winter temperatures means it is less likely that soils are frozen, even if snowpack exists. If intense rain falls on snow at low- to mid-elevations when snowpack is present *and* soils are unfrozen, there is a greater risk of landslide. The projected increase in extreme precipitation events, during summer or winter, will also increase the risk of landslides.

Development Trend Impacts

Landslide events do not typically affect large areas of populations like earthquakes or drought can; however, they can have a devastating impact on the local level. In 2013, one rock fall in St. George injured a person in their house and another rock fall in Rockville killed two people also in their home.

Some communities like Rockville have built their homes in high landslide susceptibility areas and will continue to experience the threat of rock falls. Several of Salt Lake County's developing areas are near or on landslide risk areas such as South Mountain. Developers are building homes up high along the benches of the Wasatch Front, closer to potential landslide high risk areas. This has been a trend for several years.

Many cities in Utah, Davis, Weber and Morgan Counties have had high growth and continue to develop in landslide risk areas. Some such as Salt Lake County and Layton have ordnances in place to reduce development in high risk areas. The UGS and DEM continue to work with communities in developing and adopting hillside development ordinances.

8.3 Assessment of State Geological Hazard Vulnerability and Potential Losses

State facilities data was provided by the Utah Division of Risk Management. The data presented in this update plan was complied with the help of several state agencies and entities. A state-owned facilities shape file was overlaid on top of a UGS landslide susceptibility shape file. Using ESRI ArcMap GIS, landslide susceptibility areas were clipped from a county shape files for each Utah County. The "select by location" option was then utilized in order to determine how many vulnerable state facility structures exist per county.

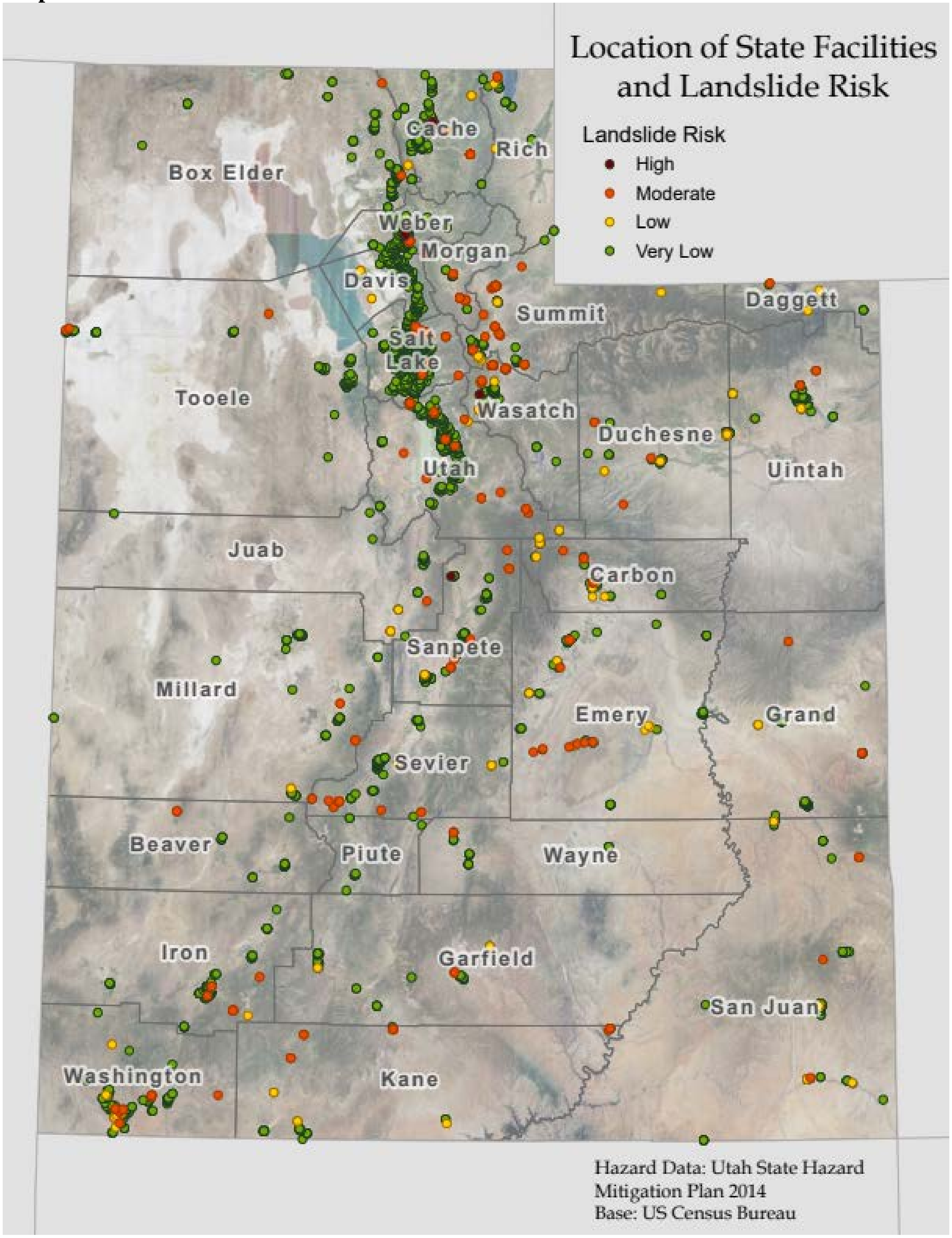
The counties with the highest number of state facilities in landslide susceptibility areas include: Salt Lake (1233), Cache (550), Utah (531), Weber (281), and Davis (2390 counties. The total value of state facilities in landslide susceptibility areas is over $16 billion dollars.

Table 8. Total Number of State Owned Facilities in Landslide Susceptibility Areas

State Facilities in Landslide Susceptibility Areas with Insured Values

County	*Total State Facilities in Landslide Susceptibility Areas*	*Total Insured Value*
Beaver	33	$41,030,093
Box Elder	179	$294,946,357
Cache	550	$2,585,128,531
Carbon	107	$153,155,928
Daggett	20	$3,415,881
Davis	239	$1,176,673,788
Duchesne	58	$37,604,577
Emery	103	$40,138,159
Garfield	47	$18,818,080
Grand	78	$62,706,393
Iron	222	$473,444,544
Juab	42	$13,522,050
Kane	50	$14,991,804
Millard	75	$82,927,079
Morgan	45	$24,180,028
Piute	10	$3,776,896
Rich	39	$9,269,610
Salt Lake	1233	$6,108,839,332
San Juan	114	$112,120,793
Sanpete	201	$437,847,695
Sevier	132	$208,487,477
Summit	108	$155,679,856
Tooele	88	$296,102,019
Uintah	119	$262,426,261
Utah	531	$2,114,961,718
Wasatch	168	$103,629,360
Washington	211	$624,007,260
Wayne	33	$4,730,187
Weber	281	$1,150,076,067
Total	**5116**	**$16,614,637,823**

Map 22. Location of State Facilities and Landslide Risk



Hazard Data: Utah State Hazard Mitigation Plan 2014
Base: US Census Bureau

Table 9. Statewide Percent of Problem Soils

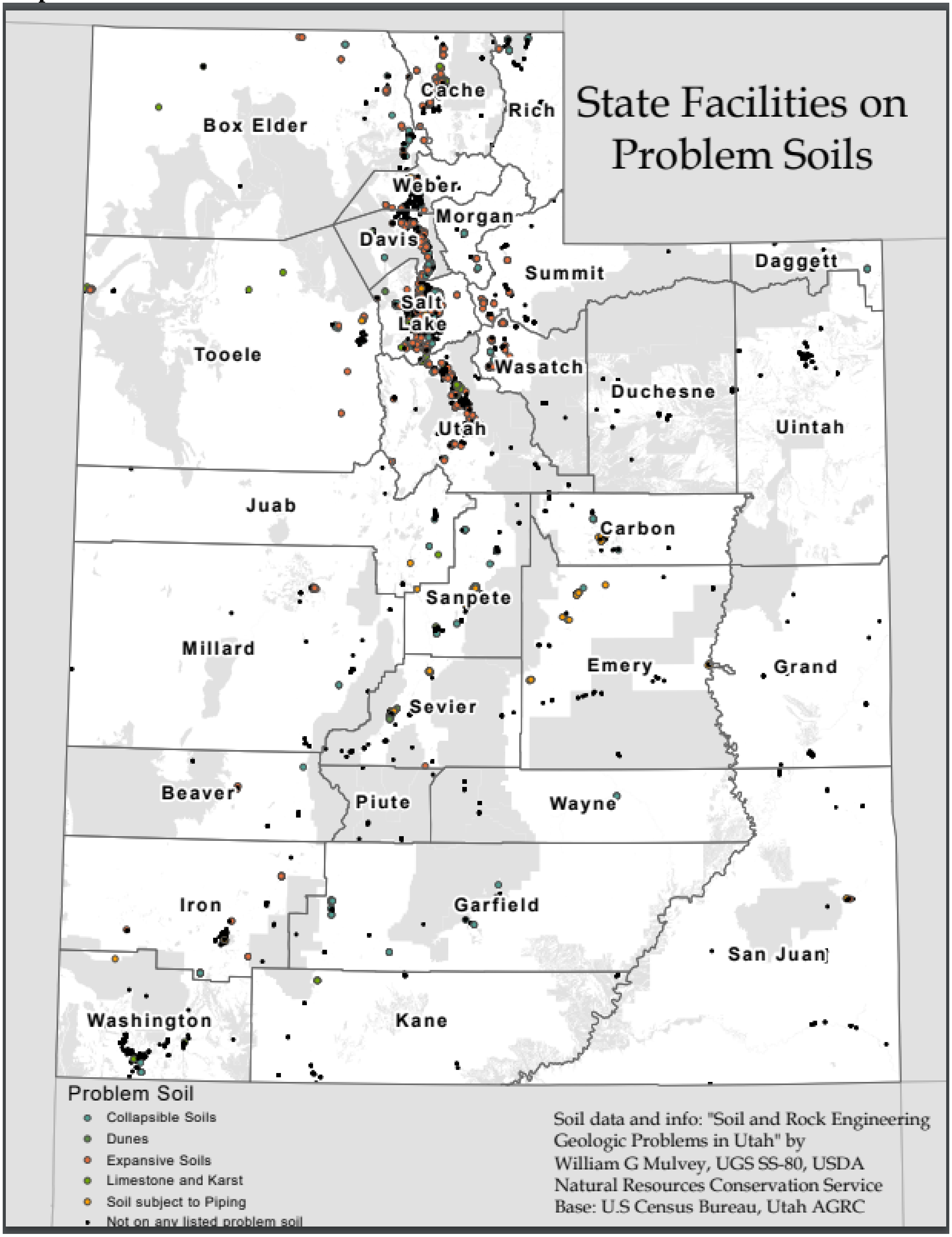
Percent Problem Soils out of Total Classified Problem Soils- STATEWIDE				
Classified Problem Soil	*Area in sq meters*	*Area in Acres*	*Ratio*	*Percent*
Peat	13,130,100	3234.506	0.000346228	0.034622792
Dunes	2,988,049,500	737,369.2334	0.078791949	7.879194863
Expansive Soils	16,258,603,500	3,998,043.104	0.428723504	42.8723504
Collapsible Soils	4,918,077,000	1,202,755.74	0.12968489	12.96848899
Gypsiferous	555,967,800	135,847.2338	0.014660328	1.46603282
Piping	6,852,340,800	1,629,998.038	0.180689538	18.06895382
Limestone & Karst	6,337,116,000	1,547,991.261	0.167103563	16.71035632
Total	37,923,284,700	9,255,239.115		

An analysis of the number of state facilities on the different types of problems soils, shows that expansive soils represents the greatest risk to the highest number of state facilities with 922 state facilities lying on expansive soils. Collapsible Soils is the next highest with 399 state facilities.

Table 10. State Facilities on Problem Soils

Number of State Facilities on Classified Problem Soils- STATEWIDE	
Classified Problem Soil	*Number State Facilities*
Peat	0
Dunes	18
Expansive Soils	922
Collapsible Soils	399
Gypsiferous	0
Piping	161
Limestone & Karst	230
Total	1730

Map 23. State Facilities on Problem Soils



Soil data and info: "Soil and Rock Engineering Geologic Problems in Utah" by William G Mulvey, UGS SS-80, USDA Natural Resources Conservation Service
Base: U.S Census Bureau, Utah AGRC

An analysis of state-owned facilities within near a Quaternary fault shows that 1232 facilities are located within 0.5 miles of a fault. Salt Lake County has the highest number of state facilities with 0.5 miles of a Quaternary fault with 666 state-owned facilities. This is followed by Weber County (97), Utah County (79), Box Elder County (63), and Sevier County (48).

Table 11. State-Owned Facilities near a Quaternary Fault

State-Owned Facilities near a Quaternary Fault with Insured Values		
County	**Facilities within 0.5 miles of a Quaternary Fault**	**Insured Value of State Facilities**
Beaver	16	$19,565,659
Box Elder	63	$148,204,094
Cache	36	$43,220,498
Carbon	17	$1,006,377
Daggett	0	$0
Davis	29	$150,923,562
Duchesne	0	$0
Emery	0	$0
Garfield	0	$0
Grand	24	$23,768,696
Iron	28	$57,398,227
Juab	21	$10,386,009
Kane	0	$0
Millard	14	$1,454,891
Morgan	16	$1,258,841
Piute	0	$0
Rich	33	$732,063
Salt Lake	666	$3,944,106,576
San Juan	0	$0
Sanpete	1	$30,000
Sevier	48	$131,697,211
Summit	12	$51,820,551
Tooele	0	$0
Uintah	0	$0

Utah	79	$241,509,453
Wasatch	20	$3,649,770
Washington	12	$43,364,091
Wayne	0	$0
Weber	97	$531,790,574
Total	**1232**	**$5,405,887,143**

An analysis of state-owned facilities in liquefaction potential areas shows that 1316 facilities are located in moderate to high liquefaction potential areas. Salt Lake County has the most state-owned facilities in high to moderate liquefaction potential areas with 609 facilities. This is followed by Utah County with 232, Davis County with 205, and Weber County with 147 facilities.

Table 12. State-Owned Facilities near a Quaternary Fault

State-Owned Facilities in Moderate to High Liquefaction Potential Areas		
County	**Facilities in Moderate to High Liquefaction Potential Areas**	**Insured Value of State Facilities**
Beaver	0	$0
Box Elder	107	$116,502,781
Cache	16	$32,473,646
Carbon	0	$0
Daggett	0	$0
Davis	205	$1,152,452,389
Duchesne	0	$0
Emery	0	$0
Garfield	0	$0
Grand	0	$0
Iron	0	$0
Juab	0	$0
Kane	0	$0
Millard	0	$0
Morgan	0	$0
Piute	0	$0
Rich	0	$0
Salt Lake	609	$2,531,694,231
San Juan	0	$0

Sanpete	0	$0
Sevier	0	$0
Summit	0	$0
Tooele	0	$0
Uintah	0	$0
Utah	232	$1,088,467,139
Wasatch	0	$0
Washington	0	$0
Wayne	0	$0
Weber	147	$478,182,121
Total	**1316**	**$5,399,772,307**

8.4 Geological Hazards Mitigation Efforts

Utah can live and deal with geologic hazards by understanding what they are, where they exist, how large or difficult they are and how to effectively mitigate them.

GEOLOGIC HAZARD DATA RESOURCES

Utah Geological Survey, Geologic Hazards Program

The UGS, Geologic Hazards Program (https://geology.utah.gov/about-us/geologic-programs/geologic-hazards-program/) has published and compiled a wide range of geologic-hazard-related publications, maps and data that is available online. Information includes geologic-hazard reports relevant to surface-fault-rupture, landslide, debris-flow, land-subsidence and earth-fissure and rock fall hazards in Utah; published UGS geologic-hazard maps, reports and site-specific studies, geologic maps, hydrogeology publications, historical aerial photography, groundwater data, photographs of geologic hazards, relevant non-UGS publications and links to external geologic-hazard-related websites.

UGS Geologic Hazards Mapping Initiative

The UGS, Geologic Hazards Program, Geologic Hazards Mapping Initiative develops modern, comprehensive geologic-hazard map sets on U.S. Geological Survey (USGS) 1:24,000-scale quadrangles in urban areas of Utah as PDFs and full GIS products.[16] These map sets typically include 10 or more individual geologic-hazard maps (liquefaction, surface-fault rupture, flooding, landslides, rock fall, debris flow, radon, collapsible soils, expansive soil and rock, shallow bedrock and shallow groundwater. Some quadrangles may have more maps if additional geologic hazards are identified within the mapped area. The Magna and Copperton quadrangle map sets within Salt Lake Valley have been

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[16] Bowman and others, 2009; Castleton and McKean, 2012

published, with mapping continuing in Cedar, Salt Lake and Utah Valleys.[17] Similar UGS geologic-hazard map sets are available for the St. George–Hurricane metropolitan area,[18] Moab quadrangle[19] high-visitation areas in Zion National Park[20] and the State Route 9 corridor between La Verkin and Springdale.[21] Detailed surface-fault-rupture-hazard maps have been published for the southern half of the Collinston, Levan and Fayette segments of the WFZ.[22] Maps for the entire WFZ are planned to be published in 2018 and for the East and West Cache fault zones in 2019. The UGS routinely partners with local governments to expedite the publication of geologic-hazard special study maps in critical areas.

UGS Geologic-Hazard Investigation and Report Guidelines

In 2016, the UGS published updated and new geologic hazard investigation guidelines as Circular 122: *Guidelines for Investigating Geologic Hazards and Preparing Engineering-Geology Reports with a Suggested Approach to Geologic-Hazard Ordinances in Utah.*[23] These guidelines were developed to provide recommendations for appropriate, minimum investigative techniques, standards and report content to ensure adequate geologic site characterization and geologic-hazard investigations to protect public safety and facilitate risk reduction. As the UGS revises or develops new geologic-hazard guidelines, Circular 122 will be updated, as appropriate. Users should refer to the URL link for the most geologic hazard investigation and report guidelines and related information. Since land use is regulated at the local level in Utah, all local governments should adopt these guidelines in their land development and geologic hazard ordinances as soon as possible to reduce the risk from geologic hazards to life safety, property and the economy.

UGS Data Resources

The UGS GeoData Archive System[24] contains unpublished Utah geology-related scanned documents, photographs (except aerial) and other digital materials from our files and from other agencies or organizations in one easy-to-use web-based system. Resources available to the public are in the public domain record and may contain reports such as geologic-hazard and geotechnical reports submitted to state and local governments as part of their permit review process. Reports for nearby developments can provide valuable insight into local geologic conditions and help develop appropriate and adequate investigations. Metadata describing each resource are searchable, along with spatial searching for resources that are local in nature. Reports within the system may be downloaded as text-searchable PDF files. Not all resources are available to all users due to end-user, copyright,

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[17] Castleton and others, 2011, 2014
[18] Lund and others, 2008
[19] Castleton and others, 2018
[20] Lund and others, 2010
[21] Knudsen and Lund, 2013
[22] Harty and McKean, 2015; Hiscock and Hylland, 2015
[23] https://ugspub.nr.utah.gov/publications/circular/c-122.pdf
[24] https://geodata.geology.utah.gov

and distribution restrictions. Users are also encouraged to search the UGS Library (https://geology.utah.gov/library/) for books and similar materials.

While the UGS website provides a source of much current, published information on Utah's geology and geologic hazards, it is not a complete source for all available geologic-hazard information, and investigators should search and review other relevant literature and data as necessary.

Geologic Hazard Information

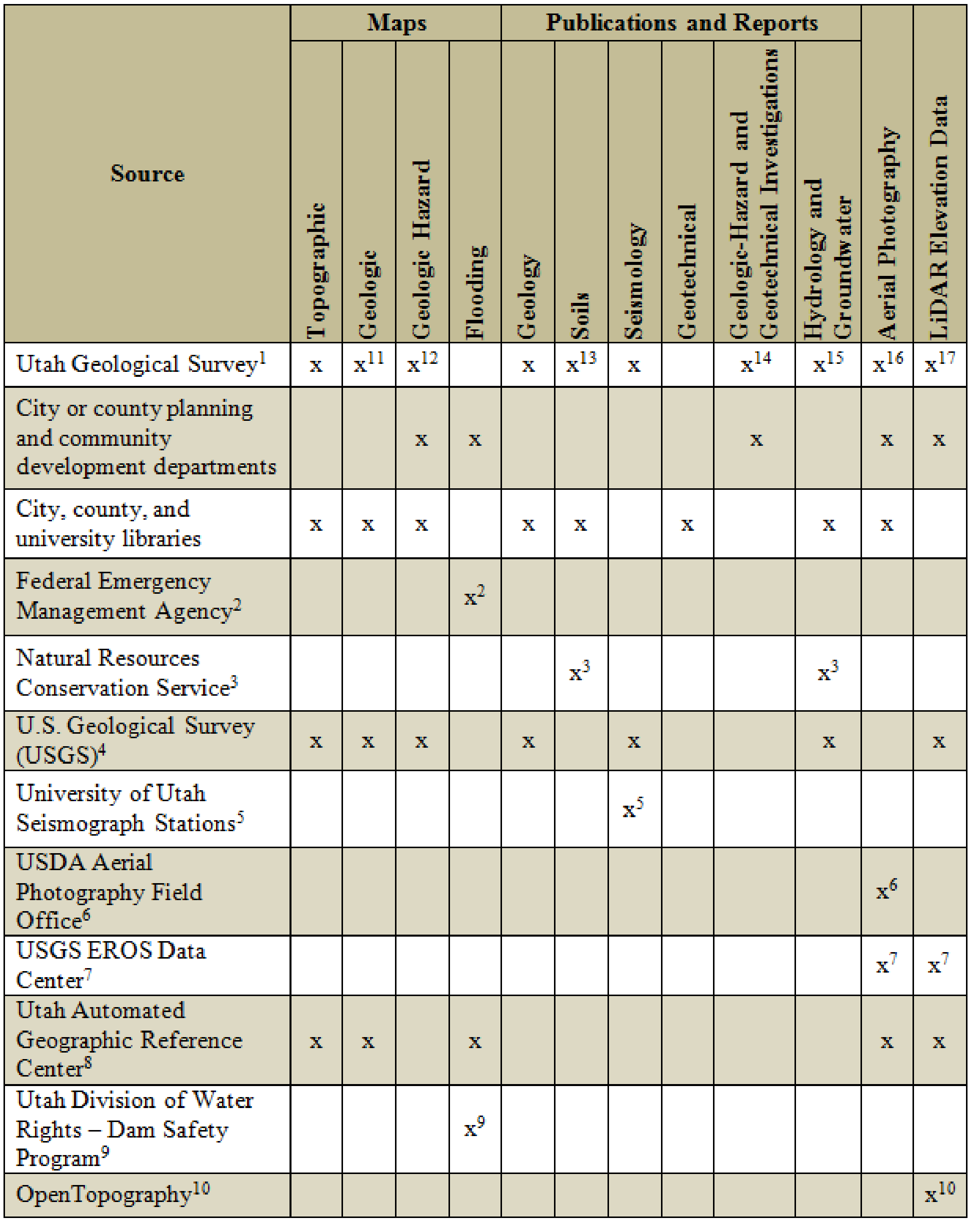
- Geologic Hazard Investigation and Report Guidelines: https://ugspub.nr.utah.gov/publications/circular/c-122.pdf.
- Geologic Hazard Maps: https://geology.utah.gov/?page_id=5104
- Geologic Hazard Publications: https://geology.utah.gov/?page_id=5275
- Geologic Information Archive: https://geodata.geology.utah.gov/
- Geologic Maps: https://geology.utah.gov/?page_id=5101
- UGS *Paleoseismology of Utah* Publications: https://geology.utah.gov/?page_id=5283

Geologic Hazards Data

- Aerial Photographs and Imagery: https://geology.utah.gov/?page_id=5147
- Community Velocity Model and Geophysical Data: https://geology.utah.gov/?page_id=6798
- Geologic-Related GIS Data: https://gis.utah.gov/data/geoscience/
- Lidar Elevation Data: https://gis.utah.gov/data/elevation-and-terrain/ and http://opentopography.org
- Utah Geochronology Database: https://geology.utah.gov/apps/geochron/
- Utah Groundwater Database: http://geology.utah.gov/?page_id=5822
- Utah Landslide Database: https://gis.utah.gov/data/geoscience/landslides/
- Utah Quaternary Fault and Fold Database: https://geology.utah.gov/apps/qfaults/index.html

The UGS is developing the *Utah Geologic Hazards Database* that will contain all of the spatial GIS data from detailed geologic hazard investigations and quadrangle map sets by the UGS. The database will be used as the source data for a new geologic hazards web mapping application with a custom report generator tool. The *Utah Quaternary Fault and Fold Database* and *Utah Landslide Database* form the first part of this new, comprehensive database.

Table 11. Potential information sources for engineering-geology investigations in Utah.



Source	Maps				Publications and Reports							
	Topographic	Geologic	Geologic Hazard	Flooding	Geology	Soils	Seismology	Geotechnical	Geologic-Hazard and Geotechnical Investigations	Hydrology and Groundwater	Aerial Photography	LiDAR Elevation Data
Utah Geological Survey[1]	x	x[11]	x[12]		x	x[13]	x		x[14]	x[15]	x[16]	x[17]
City or county planning and community development departments			x	x					x		x	x
City, county, and university libraries	x	x	x		x	x		x		x	x	
Federal Emergency Management Agency[2]				x[2]								
Natural Resources Conservation Service[3]						x[3]				x[3]		
U.S. Geological Survey (USGS)[4]	x	x	x		x		x			x		x
University of Utah Seismograph Stations[5]							x[5]					
USDA Aerial Photography Field Office[6]											x[6]	
USGS EROS Data Center[7]											x[7]	x[7]
Utah Automated Geographic Reference Center[8]	x	x		x							x	x
Utah Division of Water Rights – Dam Safety Program[9]				x[9]								
OpenTopography[10]												x[10]

1 - http://geology.utah.gov/
2 - http://msc.fema.gov/
3 - http://soils.usda.gov/survey/printed_surveys/ state.asp?state=Utah&abbr=UT
4 - http://www.usgs.gov/
5 - http://www.seis.utah.edu/
6 - http://www.apfo.usda.gov/
7 - http://eros.usgs.gov/
8 - http://gis.utah.gov/
9 - http://waterrights.utah.gov/daminfo/default.asp

10 - http://opentopography.org/
11 - http://geology.utah.gov/?page_id=5101
12 - http://geology.utah.gov/?page_id=5104
13 - https://geodata.geology.utah.gov/pages/search.php?search=!collection195
14 - https://geodata.geology.utah.gov
15 - http://geology.utah.gov/?page_id=6460
16 - http://geology.utah.gov/?page_id=5147
17 - http://geology.utah.gov/?p=19956

UTAH GEOLOGIC HAZARD REGULATIONS

The 2015 *International Building* and *Residential Code*s (IBC/IRC; International Code Council, 2014a, 2014b), adopted statewide in Utah after July 1, 2016[25] specify requirements for geotechnical investigations that also include evaluation of some geologic hazards. Local governments (Utah cities, counties, and special service districts) may also adopt ordinances related to geologic hazards that must be followed for development projects. These ordinances may also include hillside development regulations. Existing ordinances vary significantly throughout the state and it is the responsibility of the investigator to know the requirements and ordinances that apply to a site. A comprehensive geologic-hazard investigation will almost always exceed IBC/IRC and local minimum requirements.

International Building/Residential Code

The 2015 IBC/IRC specify seismic provisions for earthquake hazards. Section 1613.1 of the IBC states," *Every structure, and portion thereof…shall be designed and constructed to resist the effects of earthquake motions…*" and Section R301.1 of the IRC states, "*Buildings and structures, and all parts thereof, shall be constructed to safely support all loads, including…seismic loads as prescribed by this code*." Both the IBC and IRC assign structures, with some exceptions, to a Seismic Design Category.[26] Engineering-geology and geotechnical investigations are often needed to properly determine the seismic design parameters required to implement the code requirements. Seismic provisions of the IBC and IRC are intended to minimize injury and loss of life by ensuring the structural integrity of a building but do not ensure that a structure or its contents will not be damaged during an earthquake.

Specifically, the 2015 IBC (Section 1803.5.11) requires an investigation for all structures in Seismic Design Categories C, D, E or F to include an evaluation of slope instability, liquefaction, differential settlement and surface displacement due to faulting or lateral spreading. Although the 2015 IRC does not specifically mention liquefaction and other seismic hazards, IRC Section R401.4 leaves the need for soil testing up to the local building official in areas likely to have expansive, compressive shifting, or other questionable soil characteristics, however, investigators conducting engineering-geology or geotechnical investigations should always provide an evaluation of these hazards, and if present, provide recommendations to mitigate the hazard or risk.

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[25] Title 15A, http://le.utah.gov/xcode/Title15A/15A.html
[26] IBC Section 1613.3.5 and IRC Section R301.2.2.1

For flooding, the 2015 IBC (Section 1612.1) and IRC (Section R301.1) state that construction of new buildings and structures and additions to existing buildings and structures must be designed and constructed to resist the effects of flood hazards and flood loads. These requirements apply to construction in flood-hazard areas (Zone A and other zones identified by the local jurisdiction) identified on Flood Insurance Rate Maps by FEMA.

The 2015 IBC/IRC addresses issues related to problem soil and rock in Chapter 18, Soils and Foundations, and Chapter 4, Foundations, respectively. IBC Section 1803.5.3 and IRC Section R401.4 contain requirements for soil investigations in areas where expansive soil may be present.

For shallow groundwater, the 2015 IBC Section 1805 and IRC Section R406 contain damp proofing and waterproofing requirements for structures built in wet areas. IBC Section 1803.5.4 contains requirements for soil investigations in areas of shallow groundwater.

The 2015 IBC does not address radon hazards, however, investigators should always evaluate radon potential, and if present, provide recommendations to mitigate the risk from radon exposure. Radon Control Methods of the 2015 IRC and ASTM Standard E1465-08a *Standard Practice for Radon Control Options for the Design and Construction of New Low-Rise Residential Buildings*[27] describe radon-resistant construction techniques. The adoption of 2015 IRC and implementation of its construction techniques is at the discretion of local jurisdictions, none in Utah have adopted it to date. Regardless, radon hazard should be evaluated during a comprehensive engineering-geology investigation.

For tsunami-generated flood hazards, the 2015 IBC contains brief tsunami regulatory criteria. No tsunami hazard maps have been developed for Utah (Bear Lake, Great Salt Lake, or Utah Lake, where sub-lacustrine faults exist). The adoption of 2015 IBC is at the discretion of local jurisdictions, which none in Utah have adopted, however, tsunami hazards should be evaluated during a comprehensive engineering-geology investigation regardless for areas near Bear Lake, Great Salt Lake, and Utah Lake. The potential for ground-shaking-related seiche waves on these lakes should also be evaluated, as appropriate.

Local Government Ordinances and Requirements

A few Utah local governments have some form of geologic-hazard ordinances in place, including the counties of Salt Lake, Iron and Utah, and the cities of Cottonwood Heights, Draper, Holliday, Salt Lake and Sandy. Since land use is governed at the local governmental level in Utah, each local government needs to adopt geologic-hazard ordinances separately, leading to a patchwork of ordinances and level of geologic hazard risk reduction.

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[27] ASTM, 2009

Utah Earthquake Hazard Mitigation Legislation

(UT-1) Civil Defense Act of 1950: Authorizes the creation of the Utah Civil Defense Agency (the predecessor to Utah HLS) and the development of a statewide civil defense program. Give Utah HLS statewide authority to coordinate emergency management activities statewide.

(UT-2) Disaster Response Recovery Act, Utah Code 63-5A: Assist state and local government to effectively provide emergency disaster response and recovery assistance.

(UT-3) *Utah Code Annotated* Chapter 73 Geological and Mineral Survey-Section 68-73-6: Objectives of Survey (1) Determine and investigate areas of geologic and topographic hazards that could affect the safety of, or cause economic loss to, the citizens of this state; (f) assist local and state government agencies in their planning, zoning, and building regulations functions by publishing maps, delineating appropriately wide special earthquake risk areas, and, at the request of state agencies, review the citing of critical facilities.

(UT-4) *Utah State Office of Education (USOE) Rule R277-455 Standards and Procedures for building plan review* R277-455-4 Criteria for Approval: To receive approval of a proposed building site, the local school district must certify that: Staff of the Utah Geologic Survey have reviewed and recommended approval of the geologic hazards report provided by the school districts geo-technical consultant.

(UT-5) Emergency Management Act of 1981, Utah Code 53-2, 63-5: Establishes an emergency/disaster management system. Establishes Utah HLS. In Utah Code 53-2-104, it is stated that the Utah Division of Homeland Security shall prepare, implement, and maintain programs and plans to provide for: Prevention and minimization of injury and damage caused by disasters; Identification of areas particularly vulnerable to disasters; Coordination of hazard mitigation and other preventive and preparedness measures designed to eliminate or reduce disasters; Assistance to local officials in designing local emergency action plans; Coordination of federal, state, and local emergency activities; Coordination of emergency operations plans with emergency plans of the federal government; and Other measures necessary, incidental, or appropriate to this chapter.

(UT-6) Utah Seismic Safety Commission Act: The 13-member Utah Seismic Safety Commission (USSC) was established with the passage of House Bill 358, during the 1994 legislative session. In the 2000 legislative session, the USSC Act was amended by HB200. This amendment revised the membership of the Commission and added two additional seats. The USSC advises federal, state and local agencies and jurisdictions along with the private sector on earthquake-related policy and loss-reduction strategies. The objective of USSC is to: Review earthquake-related hazards and risk in Utah; Prioritize recommendations to identify and mitigate these hazards and risks; Prioritize recommendations for adoption as policy or loss reduction strategies; Act as a source of information for earthquake safety and promote loss reduction measures; Prepare a strategic seismic safety planning document, and Update the strategic-planning document and other supporting studies or reports. The USSC has compiled a report outlining a long-term plan to improve earthquake safety in the state of Utah entitled “A Strategic Plan for Earthquake Safety in Utah.”

(UT-7) Utah Administrative Code Rule R156-56 Utah Uniform Building Standard Act Rule: The State of Utah adopted the International Building Code IBC. By law, each jurisdiction in Utah must also adopt the IBC. This process has occurred in the majority of both urban and rural jurisdictions Utah. These higher design codes especially with regards to seismic design will greatly reduce damage to new buildings.

(Source: https://www.wsspc.org/public-policy/legislation/utah/; Information taken from the *Washington State Seismic Mitigation Policy Gap Analysis: A Cross-State Comparison*, by Scott B. Miles, Ph. D. and Brian D. Gouran, L.G.)

Utah Schools Seismic Safety Screening Bill and Program

HB 162 Utah Schools Hazard Inventory – Rep. L. Wiley was introduced into the 2008 legislative session. An appropriation of $500,000 was requested to perform a RVS of all Utah schools. The bill was eventually dismissed in the Rules Committee and had no hearing before either the House or the Senate.

The following year HB330 Utah School Seismic Hazard Inventory – Rep. L. Wiley was introduced into the 2009 legislature. It received a warm reception in the House of Representatives. However, the bill didn’t pass due to concerns of the perceived duty of responsibility to rehabilitate the identified schools.

In 2010 the bill was re---introduced as HB 072 Utah School Seismic Hazard Inventory – Rep. L. Wiley, but it also failed.

2012, two similar bills were introduced: HB271 Public School Seismic Safety Committee – Rep. L. Wiley 13 and HB279 Public School Seismic Hazard Inventory – Rep. L. Wiley 14 in the Utah legislature. Even though the bills yet again didn’t pass, lawmakers realized that advocates for safe schools were gaining strong support.

During the 2013 session, Utah lawmakers approved two significant pieces of legislation to advance the seismic safety of Utah’s school buildings.

HB 278S01 Public School Seismic Studies --- Rep. G. Froerer and the School Building Earthquake Inspection program launched a statewide initiative to begin to address the vulnerability of older schools by creating an inventory to be used to assess and prioritize these buildings. The Utah Seismic Safety Commission and Lt. Governor Greg Bell worked closely with Representative Froerer to gain the passage of HB 278S01.

HB278S01 Public Schools Seismic Studies requires that school districts requesting bond monies perform FEMA 154 Rapid Visual Screening (RVS) or more detailed studies of all their buildings constructed before 1975 and provide the results to the Utah Seismic Safety Commission (USSC).

School Building Earthquake Inspection program is a $150,000 one---time budget item that sought to perform FEMA 154 RVS on all Utah Schools.

Utah Geological Survey, Geologic Hazards Program

The UGS Geologic Hazards Program[28] is focused on reducing Utah's life safety, property and economic risk by responding to, investigating, and providing unbiased, scientific information, maps, and data about geologic hazards. Program engineering and geologic hazard geologists work on a variety of investigation, mapping, and applied research projects, along with various public outreach activities, to raise awareness, educate and inform others to help reduce Utah's risk from geologic hazards.

UGS Geologic Hazard Mapping Initiative

Development in urban areas along the Wasatch Front is proceeding at a rapid pace. In many areas geologic hazards have not been mapped and geologic-hazard ordinances have not been updated to help protect the health, welfare and safety of the public. As land well suited for development becomes scarce in many areas, development occurs in areas with more exposure to geologic hazards.

To address this issue, the Utah Geological Survey created the *Geologic Hazards Mapping Initiative* in 2008 and expanded in 2015 with funding from the Utah Legislature. The need for the initiative was highlighted during meetings of the *Geologic Hazards Working Group* formed in 2006 by Governor Jon M. Huntsman, Jr. as the result of numerous landslides during 2005 and 2006 and related issues with the development approval process in Utah.[29] The initiative provides planners, local officials, property owners, developers, engineers, geologists, design professionals and the interested public with information on the type and location of critical geologic hazards that may affect existing and future development and infrastructure. This information is presented as geologic-hazard maps for use in land-use and development planning, regulation and design in Utah as PDFs for printing and extensively attributed spatial GIS data. Geologic-hazard mapping is typically focused on areas of high projected growth or large recreational use and high hazard potential where recent quaternary/surficial geologic mapping has been completed, such as Salt Lake and Utah Valleys.

Geologic-hazard maps are typically created as map sets, based on U.S. Geological Survey 7.5-minute quadrangle topographic base maps enhanced using recent ortho aerial photography and/or lidar-derived hill shading to show topographic relief. The maps are prepared by compiling a geographic information system (GIS) database incorporating

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[28] http://geology.utah.gov/?page_id=6583

[29] https://ugspub.nr.utah.gov/publications/circular/C-104.pdf

available Natural Resources Conservation Service (NRCS) soil maps, previous geotechnical and/or geologic-hazard investigations, UGS geologic maps, lidar elevation data, FEMA flood risk maps, field reconnaissance and other data. Depending upon the specific area and availability of data, the hazard map sets[30] include maps showing:

- Earthquake Hazards
    - Surface-fault-rupture
    - Liquefaction
- Landslide Hazards
    - Landslide
    - Rock fall
- Flooding Hazards
    - Flooding and debris flows
    - Shallow groundwater
- Problem Soil and Rock Hazards
    - Breccia pipe and karst
    - Caliche
    - Collapsible soil
    - Corrosive soil and rock
    - Expansive soil and rock
    - Gypsiferous soil and rock
    - Piping and erosion
    - Radon gas
    - Shallow bedrock
    - Wind-blown sand

While site-specific geotechnical investigations should be performed for all development, the new maps identify areas where additional, specialized geologic-hazard investigations are necessary prior to development. In Utah, licensed professional geologists and professional engineers perform these investigations. The maps also provide information that may be used for emergency planning and community risk assessment for existing home and business owners.

The UGS provides copies of the published maps to local governments within the mapped areas and works with communities to help prepare geologic-hazard ordinances as requested. City and county government agencies will find the geologic-hazard maps useful in land-use planning and regulation, and for development of their own infrastructure. State and federal government agencies (such as the Utah School and Institutional Trust Lands Administration, U.S. Forest Service, and Bureau of Land Management) will find the maps useful in land management activities, permit application reviews and development of their own infrastructure. The private sector, including property owners, developers, planners, consultants and the public will find the maps useful in development project planning and design, real estate transaction due-diligence, and other activities.

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[30] https://geology.utah.gov/map-pub/maps/geologic-hazard-maps/

UGS Geologic Services for Utah Local Governments and Other Agencies

The UGS assists local governments in their planning, zoning and permitting processes by providing maps, data and technical geologic outreach and provides preliminary school site geologic hazard screening/evaluation and review of consultant prepared geologic related reports for Utah school districts.

UGS Geologic Hazard Emergency Response

Part of the UGS mission as defined in state code, is to "determine and investigate areas of geologic and topographic hazards that could affect the safety of, or cause economic loss to, the citizens of the state." This includes responding to geology-related emergency events, such as landslides, rock falls, debris flows, earthquakes and other hazards by assisting local governments and the Utah Division of Emergency Management.[31] When a geologic-related emergency occurs, local emergency managers and first responders need clear, unbiased scientific information related to the initial safety of the site. The questions used for evaluation include:

- Is the site likely safe for first responders and others to enter and work?
- What geologic information is needed to reduce the risk?
- Is geologic monitoring needed to increase safety?
- Are additional events likely to occur within a short time frame?
- Are other nearby areas at risk from geologic hazards?

The UGS Geologic Hazards Program has experienced engineering geologists who are available to provide assistance at any time to local governments and the UDEM when a geologic emergency occurs. For particularly significant emergency events, responses are managed from the UGS Emergency Operations Center (EOC) at the Utah Department of Natural Resources Building in Salt Lake City, in conjunction with the state UDEM EOC at the Utah State Capitol, the State Hazards Mitigation Team, various local governments and other agencies. Where or when mobile phone communication is unavailable, the UGS can use radio communication between the various EOCs and field staff throughout the central Wasatch Front.

Since 1850, at least 5,797 fatalities from geologic hazards have been documented in Utah and a significantly higher but undetermined number of injuries, along with billions of dollars of economic losses have occurred. In addition to numerous small geologic-hazard events, several notable events have prompted emergency response activities by the UGS in the past several years. These include the 2017 Spring Creek landslide in Riverdale, the August 2014 Parkway Drive landslide in North Salt Lake, the December 2013 rock fall in Rockville, and the 2012 Seeley fire debris flows on the Wasatch Plateau.

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[31] UDEM, https://dem.utah.gov/

After the initial emergency response, local governments are often left with uncertainty regarding what to do about the emergency event over time, how to minimize the impact to residents and others, how to reduce the risk of the current event, whether other areas are at risk and what can be done to reduce the risk of future events. The UGS provides unbiased geologic advice to local governments and the public after an event to help them make informed decisions on the potential for additional, future events, possible mitigation measures to reduce risk including what to consider in the project, known problematic geologic conditions, what qualifications are needed by professional consultants, etc., and on restricting public access to specific areas, if warranted, to protect public safety.

No Utah local governments have engineering geologists experienced with geologic hazards on staff (a few local governments have a private consulting geologist on contract), the services provided by the UGS are critical during and after geologic-hazard events. As a non-regulatory scientific agency, the UGS provides unbiased, objective geologic information to local governments and the public, so informed decisions can be made to protect the public and others from geologic hazards, including life safety, injury, financial and economic impacts.

Overall Geologic Hazards Mitigation

The mitigation strategies included in this section apply to all geologic hazards. Mitigation strategies specific to a geologic hazard are listed in the sections below.

- Continue to Support the Development of Comprehensive Geologic Hazard Map Sets

Utah's rapid growth in more geologically hazardous areas is increasing our exposure to geologic hazards, and the associated economic, life safety and quality of life impacts. This growth is resulting in increasing demands for development permitting approval from local governments, who typically have few to no technical geologic resources and information available to assist with review of proposed developments and for various local land-use and other planning initiatives.

Geologic hazard maps[32] developed and published by the UGS show the location and relative magnitude of geologic hazards that may be encountered in the mapped areas, helping permit reviewers and others involved with land-use management make informed decisions that impact large segments of our population directly from potential property damage and loss of life, or indirectly from increased costs borne by local governments and ultimately the taxpayer as a result of geologic hazard impacts such as, increased infrastructure and utility maintenance, additional liability, emergency response costs, mitigation of geologic hazards, etc.). Geologic hazards that are typically addressed by these maps, include:

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[32] https://geology.utah.gov/map-pub/maps/geologic-hazard-maps/

- Earthquake (Seismic) Hazards
    - Surface Fault Rupture Hazard and Special Study Zones
    - Liquefaction Susceptibility
- Flooding Hazards
    - Flooding and Debris Flow Hazard
    - Shallow Groundwater Susceptibility
- Landslide Hazards
    - Landslide Susceptibility
    - Rock fall Hazard
- Problem Soil and Rock Hazards
    - Breccia Pipe and Paleokarst Suscpetibility[1]
    - Caliche Susceptibility[1]
    - Collapsible Soil Susceptibility
    - Corrosive Soil and Rock Susceptibility
    - Expansive Soil and Rock Susceptibility
    - Ground Subsidence Potential[1]
    - Gypsiferous Soil and Rock Hazard[1]
    - Piping and Erosion Susceptibility
    - Geologic Radon Gas Susceptibility
    - Shallow Bedrock Potential
    - Salt Tectonics Related Ground Deformation Susceptibility[1]
    - Soluble Soil and Rock Susceptibility[1]
    - Wind-Blown Sand Susceptibility[1]

[1] – Not a geologic hazard present and mapped in all areas.

These geologic hazard maps are critical for the success of geologic hazard ordinances used for land-use and development. Without detailed and unbiased geologic hazard mapping, local governments will not have the geologic information and data they need to make informed decisions to reduce the risk from these hazards.

- Encourage Local Governments to Adopt Geologic Hazard Ordinances and UGS Guidelines

The UGS *Guidelines for Investigating Geologic Hazards and Preparing Engineering-Geology Reports, with a Suggested Approach to Geologic-Hazard Ordinances in Utah*[33] should be adopted by all local governments in their land development and geologic hazard ordinances as soon as possible to reduce the risk from geologic hazards to life safety, property and the economy. These guidelines were developed to provide recommendations for appropriate, minimum investigative techniques, standards and report content to ensure adequate geologic site characterization and geologic-hazard investigations to protect public safety and facilitate risk reduction.

- Support State of Utah High-Resolution Lidar Elevation Data Acquisition Funding

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[33] https://ugspub.nr.utah.gov/publications/circular/c-122.pdf

High-resolution topographic data from lidar elevation data is critical to mapping geologic hazards, at fine detail and high accuracy, along with being a critical data input for land-use planning and development. Also, new FEMA RiskMap flood mapping relies heavily on lidar elevation data. While the State of Utah has made great progress to acquire relevant, high-resolution lidar data, more areas need to be acquired to allow for mapping and more informed land-use and development decisions to be made. A cost-share from the USGS 3D Elevation Program (3DEP) may be available. A UGS–Utah Automated Geographic Reference Center (AGRC) collaboration typically results in annual State of Utah acquisitions with multiple local, state and federal partners.

Existing State of Utah acquisitions:
Open Topography: http://opentopography.org
AGRC: https://gis.utah.gov/data/elevation-and-terrain/

- Continue Education and Outreach on the Effects and Costs of Geologic Hazards to Utahans

Education and outreach to Utahans is critical to reduce the risk and cost from geologic hazards. Those aware of geologic hazards and their effects are equipped to help make more informed decisions when dealing with these hazards, such as in property purchase, land-use decisions, development and infrastructure design and construction and in the operation and maintenance of these properties. All Utahans have a role to play, not just those owning property, to help reduce the risk.

- Support Legislation Requiring Utah Development Regulatory Authorities to Provide Copies of Geologic-Related Reports to the UGS

Utah is dependent on the ground surface and the shallow subsurface of our state to provide a place to construct and use buildings and infrastructure and provide for water, wastewater and other resources to support a vibrant society, economy and environment. A wealth of surficial and shallow subsurface geologic data is collected annually by consultants working on geotechnical and related investigations for development and related infrastructure projects. This data is often included in technical reports as part of these investigations and submitted to local government land development regulatory authorities during the permitting process. Once submitted, the reports become part of the public record. However, these reports and data within them often become lost within the bulk of other permitting information, never to be used again or purged within a specific time frame, resulting in the loss of valuable data that could be used in the future.

Similar to the requirements for drilling new water wells by the Utah Division of Water Rights[34] legislation requiring Utah local governments to provide copies of geologic-related reports they receive to the UGS for archiving is needed. For those limited reports available

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[34] https://rules.utah.gov/publicat/code/r655/r655-004.htm#T11

to the UGS, they are archived in the *UGS GeoData Archive System*[35] for all to use. As these reports are often submitted to local governments as PDF documents, they simply need to be digitally sent to the UGS, with an insignificant cost overhead to the local government. The UGS will have some additional costs in adding the received reports into the archive, developing and reviewing metadata, and the web server and data storage costs for the system.

These archived reports will be used by the UGS in preparing new and updated geologic maps, comprehensive geologic hazard map sets and geologic hazard investigations and emergency response activities with Utah's local governments. Subsurface data will be added to a new three-dimensional (3D) shallow subsurface geologic database under development by the UGS and the Utah Department of Transportation. In addition, local governments can search the archive during land-use planning and management activities and during permit review processes to provide more information for improved decision making. Landowners, professional consultants and the public will have more information on the near-surface geology and potential geologic hazards for improved decision making. Overall, the strategy will help to reduce Utah's life safety, injury, economic and environmental risk from geologic hazards.

Reducing the Risk from Earthquake Hazards

Most earthquake hazards mitigation projects in Utah are locally determined and prioritized based on local community government needs. Part of the technical assistance provided by the State of Utah have been directed towards assisting local governments in identifying cost-effective mitigation measures that will yield the best benefits at the lowest cost in reducing their risk from earthquake hazards.

State of Utah Earthquake Hazards Agencies and Programs

The Utah Earthquake Program (UEP)[36] is a strong partnership that unites diverse professionals working cooperatively to reduce earthquake losses and risk in Utah. The Utah Seismic Safety Commission[37] (USSC) and three closely intertwined Utah state agencies, the University of Utah Seismograph Stations[38] (UUSS), the Utah Division of Emergency Management (UDEM), and the UGS Geologic Hazard Program, are the public face of the Program. Professional organizations actively partnering in the program include the Utah Chapter of the Earthquake Engineering Research Institute (EERI), the Utah Section of the American Society of Civil Engineers (ASCE), the Intermountain Section of the Association of Environmental and Engineering Geologists (AEG), and the Structural Engineers Association of Utah (SEAU).

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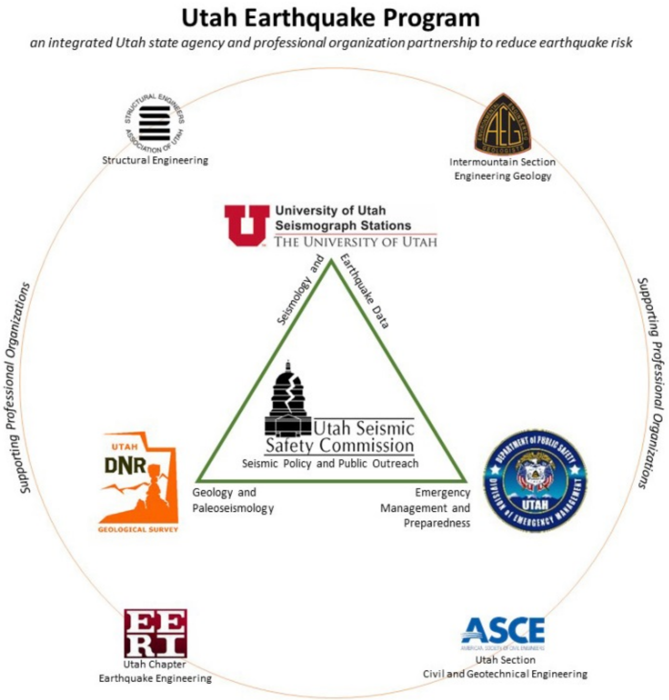
[35] https://geodata.geology.utah.gov

[36] https://ussc.utah.gov/pages/help.php?section=Utah+Earthquake+Program

[37] https://ussc.utah.gov

[38] http://quake.utah.edu/



By bringing together professionals with emergency management, engineering, geology, seismology and public outreach expertise into a collaborative framework, the Utah Earthquake Program leverages a broad array of experience, reduces duplication of effort, optimizes limited funding, and ensures the delivery of consistent, authoritative earthquake-related information for the benefit of all Utahans.

The UEP facilitates effective partnering between the State of Utah and the National Earthquake Hazards Reduction Program (NEHRP) through its constituent federal agencies: the Federal Emergency Management Agency (FEMA), the National Institute of Standards and Technology (NIST), the National Science Foundation (NSF) and the U. S. Geological Survey (USGS).

The 15-member volunteer USSC and its staff functions for state and local governments, the private sector, and the public to advance earthquake-related issues by developing, researching, and recommending seismic policies, approaches and outreach aimed at reducing Utah's earthquake hazards and managing Utah's earthquake risk. Efforts to promote earthquake safety public policy began decades ago with the Utah Seismic Safety Advisory Council (1977-1981), the Earthquake Task Force of the Utah Advisory Council on Intergovernmental Affairs (1989-1991) and the Utah Earthquake Advisory Board (1991-1994).

The Commission advises the Legislature, Governor, state and local government agencies, and the private sector on earthquake safety issues. The USSC acts as a source of information for individuals and groups concerned with earthquake safety, promotes earthquake-loss-reduction measures and legislation and implements education and awareness campaigns in order to save lives, prevent injuries, protect property and reduce social and economic disruption from the effects of severe seismic activity in Utah.

Earthquake Hazards Mitigation

In addition to the earthquake hazards mitigation strategies listed below, those strategies included in the Reducing the Risk from Geologic Hazards section above are included, along with those strategies and projects developed by the USSC in the list.

- Encourage Building Owners to Purchase Earthquake Insurance

Damages caused by most geologic hazards, including earthquakes, are typically not covered by homeowner's or other property insurance. Property owners should acquire earthquake insurance to reduce their risk of uncovered, significant financial losses after an earthquake. Owners should consider: Can they afford to repair or rebuild the damaged structure? Information on earthquake insurance in Utah is available from the Utah Insurance Department.[39]

- Increase Seismic Standards in Utah Adopted Building Codes

The currently adopted 2015 *International Building* and *Residential Code*s in Utah follow collapse prevention to allow occupants to exit buildings immediately after an event. However, this "means that the building has been pushed to the limits of its strength and stiffness and is on the verge of collapse"[40] and will likely not be usable after an earthquake. In addition, "the code acknowledges that 10% of the buildings that experience the MCER [maximum considered earthquake, the largest shaking intensity the code requires considered; not the largest possible earthquake shaking intensity] shaking intensity could collapse".[41] Increasing building code seismic standards would help to reduce building collapse and the immediate human fatalities, allow for buildings to be quickly reoccupied, so businesses and others can continue operations, thereby, significantly reducing the short- and long-term economic impact from the earthquake.

- Support Cost-Share Funding for Retrofit of Critical Infrastructure and Buildings

Continuing support of the Federal Emergency Management Agency (FEMA) Pre-Disaster Mitigation Grant program[42] is crucial to retrofitting critical infrastructure and buildings in Utah.[43] This infrastructure will be heavily relied upon immediately after an earthquake.

- Support Low-Interest Loan/Grant Programs for Retrofit of Other Infrastructure and Buildings

Programs, such as the Salt Lake City *Fix the Bricks,*[44] supports seismic improvements to eligible residential unreinforced masonry (URM) buildings. These programs can help spur the public into retrofitting their buildings and related infrastructure, reducing the risk from earthquakes.

- Adopt *International Building Code*, Statewide for Ground Shaking Hazard

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[39] https://insurance.utah.gov/consumer/auto-home/disaster-prep/earthquake

[40] Maxfield, 2015

[41] Maxfield, 2015

[42] https://www.fema.gov/pre-disaster-mitigation-grant-program

[43] https://dem.utah.gov/grants/non-disaster-grants/pdm/

[44] https://www.slc.gov/em/fix-the-bricks/

Adopting international building code standards for high-rise buildings will help provide valuable building performance information after an earthquake to the building owner and engineers and architects studying the effects of earthquakes on buildings. This detailed information on building performance is not often available following an event and represents a very low financial cost to the building owner during construction. Data shall also be provided to the University of Utah Seismograph Stations on request or in real-time.

- Adopt *International Building Code*, Statewide for Tsunami Hazard

Adopting international building codes will help to reduce the risk from tsunamis by saving lives and reduce infrastructure damage. While not a widespread geologic hazard in Utah, a significant hazard exists on and adjacent to Bear Lake, Great Salt Lake, and Utah Lake. Tsunami hazard maps will be adopted from those published by the Utah Geological Survey.

Utah Seismic Safety Commission (USSC)

The 15-member USSC was established with the passage of House Bill (HB) 358 during the 1994 legislative session. In the 2000 legislative session, the USSC Act was amended by HB 200. This amendment revised the membership of the Commission and added two additional seats. The USSC advises federal, state and local agencies and jurisdictions along with the private sector on earthquake-related policy and loss-reduction strategies.
The objective of the USSC is to:

- Review earthquake-related hazards and risks in Utah
- Prioritize recommendations to identify and mitigate these hazards and risks
- Prioritize recommendations for adoption as policy or loss reduction strategies
- Act as a source of information for earthquake safety and promote loss reduction measures
- Prepare a strategic seismic safety planning document
- Update the strategic-planning document and other supporting studies or reports

Reducing the Risk from Landslides

As the population base of Utah continues to expand into areas that are susceptible to landslides, damage and economic costs of this natural geologic process increase. Recognition of landslide risk prior to development and implementation of appropriate land-use planning and landslide mitigation measures are the most effective means to reduce their hazards. Many hillslopes are prone to landslides, particularly where development has taken place on existing landslides or where grading has modified a slope and reduced its stability. In Utah, nearly all recent landslides have occurred as reactivations of pre-existing landslides. Therefore, historical landslides, prehistoric landslides, and steep slopes prone to land sliding must be thoroughly investigated prior to development activities, along with regional groundwater and landscape and other irrigation activities.

When considering development on a hillslope or adjacent area property, owners should consult with local planning and building officials, nearby property owners, geotechnical consultants and the UGS knowledgeable about previous landslides and local landslide susceptibility before building in these areas. Before and during development activities, recognition of potential landslide activity and implementation of required engineered mitigation measures necessary to improve the stabilization of slopes can reduce landslide risk. The UGS recommends site-specific geotechnical investigations and hazard assessments for all new development. These assessments must be performed by Utah-licensed Professional Geologists (specializing in engineering geology) and Professional Engineers (specializing in geotechnical engineering) and should follow the UGS *Guidelines for Evaluating Landslide Hazards in Utah*.[45] If landslide hazards are present, the professionals should disclose the hazards and provide appropriate recommendations for grading, groundwater control, project design and construction that will reduce the hazards.

Landslide Hazards Mitigation

In addition to the landslide hazards mitigation strategies listed below, those strategies included in the Reducing the Risk from Geologic Hazards section above are included.

- Reduce Excessive Landscape Irrigation and the Use of Secondary Water Meters and Smart Irrigation Controllers

Excessive irrigation can easily cause a neighbor near or on a slope to lose their home from a landslide by increasing the groundwater table. The use of very-low water xeriscape landscaping and smart irrigation controllers that adjust the amount of water applied to landscapes, based on weather, plant and turf and soil data can significantly reduce the amount of excess water that percolates through the soil as groundwater and save money. Excessive landscape irrigation likely caused the 2017 Spring Creek Road landslide in Riverdale.[46] The use of secondary water meters will provide valuable monthly water use data to property owners and managers,[47] who can then adjust water use. Unfortunately, 2018 Senate Bill 204[48] that would phase in the use of secondary water meters did not pass and was not enacted.

Various rebates are available from Utah's water conservancy districts for smart irrigation controllers and other water saving devices for landscape irrigation that reduce water use and save Utahans money.

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[45] https://ugspub.nr.utah.gov/publications/circular/c-122.pdf
[46] https://geology.utah.gov/hazards/landslides-rockfalls/spring-creek-road-landslide/
[47] Larson, 2018
[48] https://le.utah.gov/~2018/bills/static/SB0204.html

  - Central Utah Water Conservancy District (http://rebates.cuwcd.com/): Salt Lake, Utah, Wasatch, Duchesne, Uintah, Sanpete, and parts of Summit and Juab Counties.

  - Washington County Water Conservancy District: (http://www.wcwcd.org/conservation/programs/water-smart-irrigation-rebate-program/)

  - Weber River Water Conservancy District (http://weberbasin.com/index.php/rebates/rebates): Davis, Morgan, Weber, and most of Summit County.

- Encourage Local Governments to Restrict or Prohibit Development in Landslide-Prone Areas

Local government landslide-hazard overlay zones can be developed using available maps and data to more effectively regulate or prevent development in landslide-prone areas. Often, the costs of urban landslides are borne by the local government and ultimately, the taxpayer, utility companies or customers, and the property owners long after the property has been developed. These overlay zones can help reduce the shifting of costs to the taxpayer, utilities and property owners.

- Continue UGS Landslide Monitoring in Partnership with Local Governments

The UGS Geologic Hazards Program monitors various Utah landslides (Chalk Creek Road, Sherwood Hills, Springhill, Parkway Drive, etc.) in cooperation with local governments. This project provides valuable reconnaissance information to local governments, residents and the public in dealing with landslide hazards in their communities. Monitoring information often consists of photographs, GNSS movement monitoring, and groundwater level data archived in UGS databases such as the *UGS GeoData Archive System* and the Utah Groundwater Monitoring Network.

- Develop Real-Time GNSS Monitoring of Critical Landslide Areas

Real-time GNSS movement monitoring of critical landslide areas would be helpful to provide continuous data on landslide movement and warning of landslide movement increases that could trigger evacuations. The landslide complexes along State Route 14 east of Cedar City, landslides along State Route 226, the Thistle and Shurtz Lake landslides near U.S. Highway 6 and the Green Lakes landslide southeast of Cedar City are several potential locations for real-time movement monitoring to protect the public. The UGS and AGRC's The Utah Reference Network (TURN) have the capability to monitor landslides in real-time with sufficient on-going funding.

Reducing the Risk from Flooding Hazards

Flooding, other than debris flows, alluvial fan flooding and shallow groundwater are discussed in the Flooding Hazard chapter. Flooding continues to affect property outside of established flood hazard zones, mainly due to outdated mapping, topographic, building and infrastructure changes made after flood map publication, climate change and the increase in generally impermeable ground surfaces due to urbanization.

Flooding Hazards Mitigation

In addition to the flooding hazards mitigation strategies listed below, those strategies included in the Reducing the Risk from Geologic Hazards section above are included.

- Continue Detailed Debris Flow and Alluvial Fan Flooding Hazard Mapping and Analysis

FEMA Flood Rate Insurance Maps (FIRM) typically do not show the hazard posed from debris flows and alluvial fan flooding. As development in Utah continues to move onto alluvial fans near steep mountain fronts, the risk from debris flows and alluvial fan flooding will increase significantly. Detailed mapping of these hazard areas performed as part of the UGS process to develop comprehensive geologic hazard map sets is critical in identifying the debris flow and alluvial fan flooding hazard for use in land-use planning, siting of debris basins and other mitigation and in the design of engineered mitigation structures.

- Encourage Local Governments to Construct and Maintain Debris Basins in Hazard Areas

Debris basins are critical to mitigate the risk from debris flows and alluvial fan flooding, particularly in already urbanized areas if suitable locations are available at the mouths of drainage canyons. Additionally, local governments must commit to routine maintenance and clean out of debris basins and related structures so they are functional for the next event. Detailed debris flow mapping is part of the necessary geologic inputs to debris basin and related structure engineering design. The UGS can provide geologic mapping and input data for debris basin engineering design, similar to that provided for Centerville Canyon.[49]

Reducing the Risk from Problem Soil and Rock Hazards

Most problem soil and rock hazards affecting current development and infrastructure can be traced back to a lack of or an incomplete comprehensive geologic-hazard and geotechnical investigation where the development and infrastructure design did not incorporate the recommendations presented in the investigation final report. While no

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[49] Giraud and Castleton, 2009

deaths have been reported in Utah from problem soil and rock hazards other than radon gas, they have caused an undetermined, but very significant, amount of infrastructure damage, inconvenience, and resulting negative economic impact.

Problem Soil and Rock Hazards Mitigation

Nearly all problem soil and rock hazards can be mitigated by requiring geologic-hazard and geotechnical investigations when the recommendations are incorporated into infrastructure project design and construction. In addition to the problem soil and rock hazards mitigation strategies listed below, those strategies included in the Reducing the Risk from Geologic Hazards section above are included.

- Adopt Groundwater Basin Management Plans for Land Subsidence and Earth Fissure Hazard

In valleys where groundwater mining leading to land subsidence and earth fissures is occurring, dewatering of fine-grained layers in basin-fill aquifers is the principal cause of aquifer compaction and associated land subsidence and earth-fissure formation. If aquifer compaction is to be avoided, basin-fill aquifers should be managed to balance groundwater recharge and discharge at both local and basin wide scales. There are several ways to accomplish this goal, including (1) increasing overall water resources by importing water from other basins, (2) increasing groundwater recharge to the basin-fill aquifer through conjunctive management of ground- and surface-water resources, (3) dispersing high discharge wells to reduce localized land subsidence, and (4) reducing overall groundwater withdrawals in a basin. Information on groundwater basin management plans for land subsidence and earth fissure hazard is available.[50]

- Adopt *International Residential Code* Statewide for Radon Gas Hazard

Adopting *International Residential Code* Statewide for Radon Gas Hazard standards will help to significantly reduce the hazard and risk from radon gas, Utah's most deadly geologic hazard, by sealing foundations and venting the building foundation subgrade soils, allowing the upward flowing radon gas to be dissipated harmlessly into the air above the building. Typical costs for adopting radon-resistant construction measures are around $500 in the construction of a new residential home. Whereas, active radon mitigation systems installed after the time of construction typically range from $1,200 to $1,700.

For a 72-year old diagnosed with lung cancer in 2000, the cost of the first six months of care ranged from $16,122 (no active treatment) to $56,160 (chemo-radiotherapy) and varied by stage at diagnosis and histologic type.[51] Based on an approximate average of about 50 deaths a year (not including those with radon-induced lung cancer, that did not die that year) from radon gas in Utah around 2000, the resulting minimum societal

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[50] Knudsen and others 2014

[51] Cipriano and others 2011

economic cost ranged from $806,100 to $2.8 million, just for the initial care in one year. The increase in building construction cost in mitigating radon gas can easily be offset by the overall cost to society.

Reducing the Risk from Volcanic Hazards

In addition to the volcanic hazards mitigation strategies listed below, those strategies included in the Reducing the Risk from Geologic Hazards section above are included.

- Monitor the USGS Volcano Alert Notifications in the State Emergency Operations Center

Since the threat of volcanic hazards to Utah is most likely from an out-of-state volcanic eruption in the western U.S., monitoring of the USGS Volcano Alert Notification System[52] can provide advance warning of an advancing ash cloud that could affect Utah. Should an ash cloud that could affect Utah be detected, estimated ash deposition depths should be determined and if evacuation is not necessary, the public should be advised to quickly acquire adequate food and water and shelter in place for an extended time period. Less than 0.25 inch of ash on the ground can easily bring transportation to a standstill and short out above-ground electrical transmission lines. The Federal Aviation Administration (FAA) will likely issue flight advisories and close the airspace in and near to the ash clouds for public life safety.

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[52] https://volcanoes.usgs.gov/vhp/notifications.html

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