# Scenario for a Magnitude 7.0 Earthquake on the Wasatch Fault–Salt Lake City Segment

## Hazards and Loss Estimates

Developed by the
Earthquake Engineering Research Institute,
Utah Chapter

Prepared for the
Utah Seismic Safety Commission

June 4, 2015

"Plans are worthless, but planning is everything. There is a very great distinction because when you are planning for an emergency you must start with this one thing: the very definition of 'emergency' is that it is unexpected, therefore it is not going to happen the way you are planning."

President Dwight D. Eisenhower, 1957

as quoted in "Resilience by Design"
Recommendations of the Mayoral Seismic Safety Task Force
City of Los Angeles, California - Mayor Eric Garcetti (2014)

**Earthquake Engineering Research Institute,
Utah Chapter, 2015
Salt Lake City, Utah**

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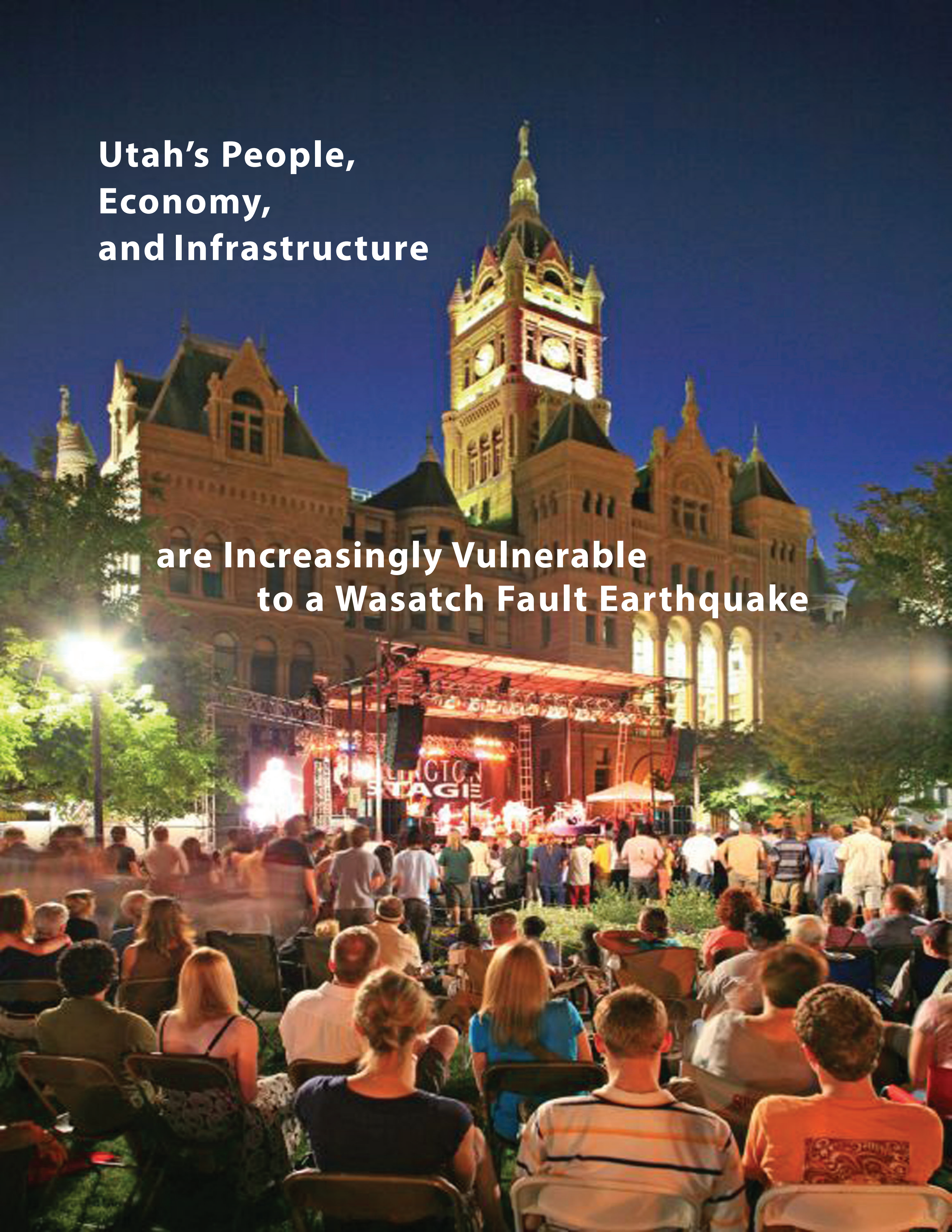
University of Utah Seismograph Stations
THE UNIVERSITY OF UTAH

# Utah's People, Economy, and Infrastructure

## are Increasingly Vulnerable to a Wasatch Fault Earthquake



# Executive Summary

Earthquakes pose the greatest natural threat to Utah's people, built environment, and economy. For planning purposes, a scenario is presented that describes the massive physical, economic, and social impacts that will result from a future large magnitude 7.0 earthquake on the Salt Lake City segment of the Wasatch fault. The concentration of population, infrastructure, and economic activity in the Wasatch Front urban corridor, literally astride the Wasatch fault, aggravates Utah's earthquake vulnerability.

**Earthquakes pose the greatest natural threat to Utah's people, built environment, and economy**

A key aim of this report is to present a realistic picture of the effects of the Wasatch fault scenario earthquake—in particular, how long it may take the state of Utah and its residents to fully recover and the potential long-term impacts on Utah's economy. This report was developed by the Utah Chapter of the Earthquake Engineering Research Institute with assistance from earthquake professionals in the Utah community. Funding was provided by the Federal Emergency Management Agency (FEMA). Our primary audience is the Utah Seismic Safety Commission, whose mission is to identify earthquake-related hazards and risks to the state of Utah and its inhabitants and to promote actions that will mitigate these hazards and risks to reduce earthquake losses. More broadly, this report is intended to inform policy makers, emergency managers, and the general public.

The ultimate goal of this report is to catalyze public and private actions that will increase pre-disaster resiliency through earthquake preparedness—being prepared to WITHSTAND, to RESPOND, and to RECOVER. Prepared to WITHSTAND requires: the strengthening of weak buildings to reduce loss of life and injury; addressing the seismic vulnerability of schools and government-owned buildings; encouraging more robust building design; and reducing potential interruptions to business operations and essential services. Prepared to RESPOND requires: understanding the scope of disaster-response needs; anticipating loss of utilities; exercising response plans; anticipating the need to inspect, in a timely way, hundreds of thousands of buildings for safe occupancy; and adopting policies that will facilitate fast and thorough post-earthquake inspections of buildings that house vital businesses and essential services. Prepared to RECOVER requires: establishing beforehand laws, rules, and ordinances that address issues foreseeable in circumstances of disaster recovery; planning for resiliency to recover at individual, family, and community levels; developing continuity plans for businesses and schools; planning to provide essential utilities on a temporary basis; and planning for restoring essential utilities on a permanent basis.

The scenario earthquake is a real verifiable threat. At least 22 large surface-faulting earthquakes ("Big Ones") of about magnitude 7 have occurred during the past ~6,000 years, about once every 300 years on average, along one of the five central segments of the Wasatch fault between Brigham City and Nephi. The average repeat time of Big Ones on the Salt Lake City segment is about 1,300–1,500 years. The last one occurred around 1,400 years ago—enough time for strain energy to build up to unleash another.

**The estimated short-term economic loss is over $33 billion**

The expected severity and distribution of strong ground shaking during the scenario earthquake is modeled using the U.S. Geological Survey's ShakeMap computer program. As a result of rupture of the entire Salt Lake City segment of the Wasatch fault, most of the Salt Lake Valley will experience severe ground shaking; strong potentially damaging ground shaking will extend along the Wasatch Front urban corridor from southern Utah Valley to north of Ogden. Besides ground shaking, other physical effects associated with the scenario earthquake will include: rupture of the ground surface (up to 8 feet vertically) along the trace of the Wasatch fault from Draper to North Salt Lake; widespread liquefaction of sediments in lowland areas of the Salt Lake Valley, potentially damaging structures and facilities; perhaps hundreds of landslides and rockfalls, especially under wet conditions, in areas of steep rock slopes and river embankments that experience strong to severe ground shaking; and extensive ground subsidence, possibly resulting in flooding by the Great Salt Lake, depending on lake level.

**More than 84,000 households are expected to be displaced with nearly 53,000 individuals seeking shelters**

Hazus is a standardized, nationally applicable software package developed by FEMA for loss and risk assessment associated with earthquakes, hurricanes, and floods. A pivotal part of this report addresses the economic and social impacts of the scenario earthquake, using Hazus and Geographic Information Systems (GIS) technology. Aggregate loss estimates are for a region that encompasses Utah's 12 most northern counties: Box Elder, Cache, Davis, Juab, Morgan, Rich, Salt Lake, Summit, Tooele, Utah, Wasatch, and Weber.

**There will be a need to evaluate for safe occupancy more than 300,000 structures in 30 days, which will require about 2,400 building inspectors**

Loss estimates for the scenario earthquake indicate disastrous impact. The estimated short-term economic loss is over $33 billion. This includes (1) direct building-related capital losses (including structural, non-structural, content, and inventory) of $24.9 billion, (2) income losses of $6.9 billion, and (3) lifeline-related losses of $1.4 billion. More than 84,000 households are expected to be displaced with nearly 53,000 individuals seeking shelters. Depending on the time of day, there will be an estimated 2,000 to 2,500 deaths, and the estimated number of people injured and needing hospital care ranges from 7,400 to 9,300. Essential lifelines such as water, electricity, gas, and sewer will be disrupted for days to months, and in some locations in the Salt Lake Valley, perhaps longer. An example challenge will be the need to evaluate for safe occupancy more than 300,000 structures in 30 days, which will require about 2,400 building inspectors. Another challenge will be the removal of debris generated by the earthquake—requiring over 820,000 truckloads at 25 tons per truck.

**Essential lifelines such as water, electricity, gas, and sewer will be disrupted for days to months, and in some locations in the Salt Lake Valley, perhaps longer**

For response planning, an operational picture of the scenario earthquake disaster is provided by Hazus maps variously showing the expected distribution of damaged buildings, displaced households, highway infrastructure impacts, impaired hospitals and hospital bed availability, potential search and rescue needs, and the location of care facilities for the elderly. Similarly, for recovery planning, Hazus maps are presented that show the distribution of direct building economic losses; likely damaged electrical, natural gas, and oil facilities; concrete and steel debris and associated haulage implications for highways; and the distribution of non-English speaking populations (for communicating disaster-related information).

**Nine recommendations to improve seismic safety and resiliency conclude the report**

The conclusion of the report is a call to action—to make Utah and its communities more resilient to earthquake disaster. Utah is NOT prepared for a major Wasatch fault earthquake. We end with nine recommendations to the Utah Seismic Safety Commission that are intended to stimulate and guide discussion with public officials and all stakeholders for effective action and change.

# Purpose and Objectives

## Introduction

Earthquakes pose the greatest natural threat to Utah's people, built environment, and economy. In the Wasatch Front region, several hundred earthquakes per year are recorded, most of them less than magnitude 3 on the Richter scale. The dominant source of the danger is the Wasatch fault, which periodically unleashes "Big Ones" (large surface-faulting earthquakes of about magnitude 7) about once every 300 years on average along one of the fault's five central segments between Brigham City and Nephi—the most active parts of the fault.

Most of Utah's population is concentrated in the Wasatch Front urban corridor, literally astride the most active segments of the Wasatch fault (Figure 1). This circumstance of "lots of eggs in one basket"[1] underscores Utah's vulnerability to a large Wasatch fault earthquake.

It is difficult to imagine the massive impact an inevitable Big One in the Wasatch Front urban corridor will have—threatening life safety, causing major damage to the built environment, disrupting critical services, and jeopardizing Utah's economy. The purpose of this report is to ensure that stakeholders comprehend the enormity of such an event.

For planning purposes, we examine the consequences of a magnitude 7.0 earthquake on the Salt Lake City segment of the Wasatch fault in the Salt Lake Valley and adjacent areas. Projections based on computer modeling provide a basis for anticipating the physical, economic, and social impacts that will result from such a future earthquake.

## What is an Earthquake Scenario?

Earthquake planning scenarios provide policy makers, emergency preparedness personnel, and the public with realistic assessments of the areas of greatest impact. They also identify the types of structures and lifelines – the critical infrastructure that provides the utilities and essential services that our modern society relies on – that are most at risk of damage. Scenarios estimate building damage, building collapse, and estimate deaths and injuries.

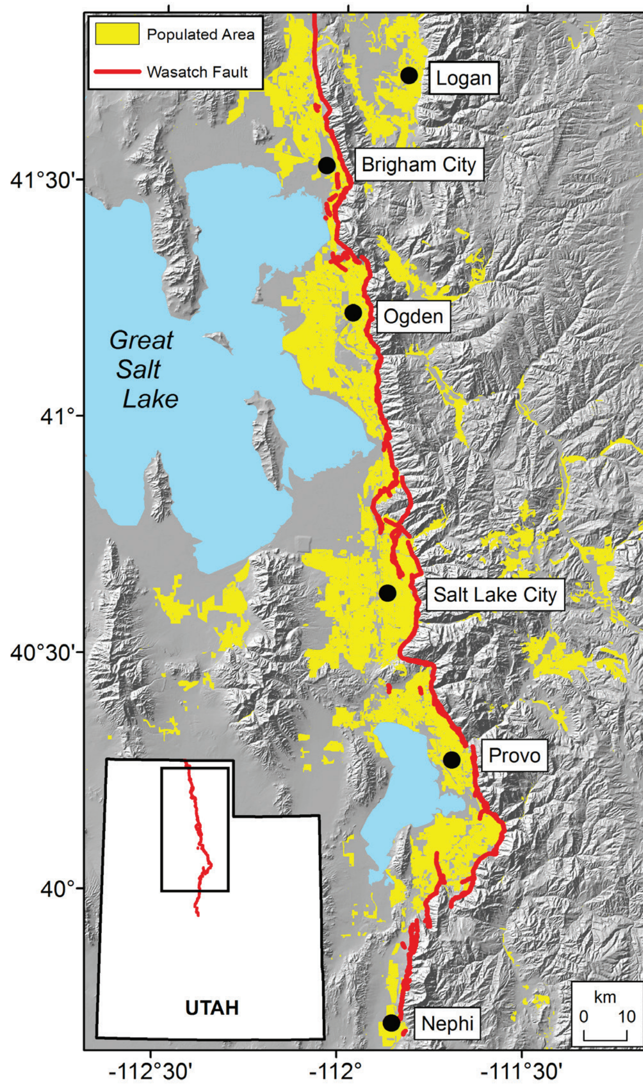



*Figure 1. Map of Utah's Wasatch Front urban corridor showing populated areas (in yellow) along the Wasatch fault (in red). Population data from 2010 (figure courtesy of the University of Utah Seismograph Stations).*

Scenarios also identify areas and infrastructure that are most likely to sustain little or no damage and remain functional following an earthquake, thereby minimizing the placement of valuable response assets in areas where they may not be needed. A scenario is not a prediction of what will happen. It is an estimation of a possible outcome.

The cost to prepare planning scenarios, and to update them regularly, is insignificant compared to the future savings from reduced losses to infrastructure, the economy, and human life when the information is used to develop effective seismic-safety policies and to increase community resiliency. Minimizing future earthquake impact through prior planning, loss-reduction measures, and providing information to help speed the recovery is critical for maintaining earthquake-resilient communities.

## Purpose of this Scenario

Will a magnitude 7 earthquake cripple our economy or will we be able to adequately recover from it? The answer depends on what we do now, before it occurs. We need to think of this as a "when it occurs" and not as a "what if it occurs" event. All Utahns need to understand that an earthquake of this magnitude is not a 72-hour event, after which everything will go back to normal.

The immediate cost of a magnitude 7 earthquake will be measured in lives lost, people injured, buildings damaged or destroyed, infrastructure damaged or destroyed, and use of land lost due to liquefaction, landslides, and surface fault rupture. However great this initial cost, there will be an even greater loss to the economy due to the loss of business function and income, loss of jobs, and the massive cost to rebuild. The social disruption is difficult to overstate. Though this report focuses on Utah's 12 most urban counties, the disaster's effects will not be confined to just the Wasatch Front. It will have impacts throughout the state, region, and nation.

This report is written for the Utah Seismic Safety Commission to assist with their mission of earthquake risk reduction, but the information contained in this scenario report can also be used by the state legislature, local governments, emergency managers, business owners, and home owners along the Wasatch Front to assist with their specific risk reduction planning.

Resiliency is a term that is used to help individuals, businesses, and communities understand how quickly they can return back to a pre-disaster state. The more resilient a community is, the faster it can recover from a disaster. Becoming more resilient does not just happen. It takes effort and planning before disaster strikes.

This report is a call to action. Everything that is done now, prior to the earthquake, will help to reduce deaths and injuries, reduce the cost of damage, streamline emergency response, improve individual response, and speed-up the recovery—all of which will better protect the vital state economy. A critical part of this effort is being able to get businesses up and running as soon as possible allowing people to get back to

**The Wasatch fault dips downward beneath the urbanized Wasatch Front Valleys. Consider the following:[2]**

- Nearly 80 percent of Utah's population lives within 15 miles of the Wasatch fault in the Wasatch Front area (see Figure 1).
- More than 75 percent of Utah's economy is concentrated in Salt Lake, Utah, Davis, and Weber counties above the Wasatch fault.
- Most of Utah's state government facilities are located within 15 miles of the Wasatch fault.
- Major interstate transportation corridors and the Salt Lake City International Airport lie above or within 15 miles of the Wasatch fault.
- By 2050 the population in the four largest Wasatch Front counties (Salt Lake, Utah, Davis, and Weber) is projected to grow to 3.7 million, an 80% increase over 2010.[3]
- To meet the needs of rapid population growth along the Wasatch Front, $14.4 billion of new transit and highway infrastructure is planned over the next three decades.

work and jump starting the economy. Another critical effort will be to get government services and schools back into operation.

This scenario report will paint a realistic picture of what will likely happen following a magnitude 7 earthquake on the Wasatch fault that can be used to improve the resilience of government, businesses, and residents. This will be accomplished in three areas of preparedness:

**Prepared to WITHSTAND**

**Prepared to RESPOND**

**Prepared to RECOVER**

Pre-disaster mitigation is the best thing that we can do to reduce the impacts and increase the speed of recovery from this disaster. In preparing for this earthquake, an ounce of prevention is worth a pound of cure, meaning that a small amount of preparation will greatly benefit the response and recovery efforts. In conjunction with the purposes listed above, it is our hope that this scenario report will encourage the accomplishment of the following objectives:

### *Prepared to WITHSTAND*

These efforts are intended to strengthen buildings and infrastructure so that they will reduce the possibility of collapse or failure and to decrease the amount of damage. These efforts will help reduce the damage losses estimated in this scenario.

**Prepared to WITHSTAND**

- Reduce Loss of Life by Strengthening Weak Buildings
- Strengthen Public Buildings to Protect Students and Government
- Reduce Economic Loss and Speed-up Recovery by Encouraging More Robust Building Design
- Reduce Economic Impact by Getting Businesses Back to Business

• Reduce Loss of Life by Strengthening Weak Buildings: One of the most significant sources of deaths, injuries, and damage resulting from a magnitude 7 earthquake is from the likely collapse of two types of buildings. The first is unreinforced masonry buildings. These are referred to as URMs. They are constructed of brick or block that does not contain any or very minimal amounts of reinforcing steel. Many older homes are constructed of URM. The second type of building is referred to as non-ductile concrete. This type of concrete building has reinforcing, but is at risk of collapse because the reinforcing steel can buckle causing the building to rapidly loose strength and then collapse. Newer seismic codes do not allow these types of buildings. These buildings should be strengthened to significantly reduce the loss of life forecast in this scenario. Public education regarding these building types must be provided to allow citizens to make informed decisions about where they live or work. Strengthening weak buildings should be a high priority.

• Strengthen Public Buildings to Protect Schools and Government: The State of Utah must exercise its responsibility to serve and protect the citizens of Utah by developing strengthening or replacement policies which address the seismic vulnerability of schools and government-owned buildings, and any other state infrastructure deemed to be vulnerable to earthquakes.

• Reduce Economic Loss and Speed-up Recovery by Encouraging More Robust Building Design: This scenario forecasts a huge economic loss from damage to code-designed buildings. These buildings are designed to prevent building collapse, but do not prevent expensive damage or displacement of occupants, and the associated economic loss. If new buildings are designed with a focus of minimizing damage rather than just preventing building collapse, they will sustain less damage, can be more easily repaired, and can be reoccupied more quickly. Those interested in maintaining occupancy following a magnitude 7 earthquake should consider designing their buildings (homes, businesses, or public facilities) to a higher standard. The state should develop education materials to inform owners, especially business owners, of the benefits of more robust building design.

• Reduce Economic Impact by Getting Businesses Back to Business: Business operations will jump start the economy after a major earthquake. The forecast economic loss to the economy due to business interruption is massive. If businesses are not operating, essential services will be missing, people will be out of work, and tax revenue will be significantly lower at a time when all of these things are needed. To stay in business, business owners must strengthen buildings, strengthen nonstructural items that could fall or fail, and protect their product or services so that their business is not shut down by earthquake damage.

### *Prepared to RESPOND*

One type of needed response following a magnitude 7 earthquake will be from first responders. These people will respond to fires, search for survivors in downed buildings, keep the peace, and restore vital utilities. Another type of response is individual. For example: We just had a magnitude 7 earthquake. You are at work, your spouse is at home, and your children are at school. How would you respond? Similar scenario questions could be asked of you as a member of a family, a leader, a school administrator, a business owner, or as a government official. Being able to answer the question is what Prepared to RESPOND means.

• Understand the Scope of Needed Response: Using this scenario report to understand the scope of disaster-response needs will assist in meaningful planning to speed up needed response.

**Prepared to RESPOND**

- Understand the Scope of Needed Response
- Prepare to be Without Utilities
- Exercise for Response
- Prepare for Building Inspection
- Adopt Policies to Get Businesses, Schools and Essential Services Back Into Their Buildings

• Prepare to be Without Utilities: What would you or your business do without electricity, gas, or water for an extended period of time? Residents, businesses, schools, churches, and communities should plan how they will respond to this important question.

• Exercise for Response: This scenario report paints a dire picture of the immediate aftermath of a major earthquake. The first week or two following this event is critical. Individuals, families, neighbors, churches, schools, communities, cities, counties, and the state must discuss their needs and plan how they will respond. This report can be used to assist in their planning. Exercises can be discussion-based where you meet and present scenarios and then discuss how you would respond, or they can be action based where you actually involve people and equipment from simple to full-scale operations.

• Prepare for Building Inspection: There will be a need to inspect about 300,000 buildings following a magnitude 7 earthquake. This will overwhelm the inspection resources of every jurisdiction. Cities, counties, and the state must plan for how to how to allocate scarce inspection resources and know how to request additional resources.

• Adopt Policies to Get Businesses, Schools, and Essential Services Back Into Their Buildings: One path to facilitate getting businesses, government, and schools back into operation, is the Building Occupancy Resumption Program (BORP). This program allows building owners to pre-certify private building inspectors for post-earthquake evaluation of their buildings. Salt Lake City and Murray City have adopted BORP (as of April 2015). It or similar policy should be adopted by all cities along the Wasatch Front.

### *Prepared to RECOVER*

Community resilience is the ability for a community to respond to and recover from a devastating event. The ability to effectively recover will be largely dependent on how well we plan for recovery. It will be a long and difficult process, but it becomes significantly easier if planned for now. Recovery follows quickly on the heels of response, but it will last for years. One of the best ways to speed-up recovery is by getting the state's economic engine going again by getting businesses back into operation. Another is to have laws, rules, and ordinances in place prior to the event.

• Establish Laws, Rules, and Ordinances that Address Issues Related to Recovery: The aftermath of an earthquake will be a very chaotic time. If the state and city government have considered essential issues and have passed the necessary laws, rules, and ordinances prior to the event, the entire recovery process will go better than if these are attempted to be passed after the fact. Consider the various issues addressed in this scenario report and in other areas that have faced rebuilding from earthquakes, like Christchurch, New Zealand.

• Plan for Recovery at the Lowest Levels: Individuals and families should look at their circumstances and understand the realities of the aftermath. They should then plan accordingly trying as much as possible to recover using their own resources. Communities should do likewise and decide what they need to do now to make the recovery process better for those in their communities.

## Prepared to RECOVER

- Establish Laws, Rules, and Ordinances that Address Issues Related to Recovery
- Plan for Recovery at the Lowest Levels
- Develop Business Continuity Plans
- Plan for Providing Temporary Essential Utilities
- Plan for Restoring Essential Utilities

- Develop Business and School Continuity Plans: In addition to strengthening weak buildings, designing more robust buildings, and preparing a BORP plan to get back into their buildings faster, businesses and schools must create continuity plans which include contingency plans. Owners who are prepared will be able to resume operations much more quickly than those who are not.

- Plan for Providing Temporary Essential Utilities: Once the dust settles and response operations are winding down, there will be an immediate need for water, power, gas, and sewage disposal. Individuals and communities who plan for and provide for these essential needs will be much better off than those who do not plan.

- Plan for Restoring Essential Utilities: Local and county government should work with private utility companies to discuss coordination and cooperation needed to restore services to Utahns in a methodical manner.

## Quick Facts

- **Utah's Economic Activity:** In 2013, Utah's Real Gross Domestic Product (Real GDP, the value of the production of goods and services, adjusted for price changes) was $131 billion. The Ogden-Salt Lake City-Provo urban corridor accounted for 85% of this Real GDP. The Salt Lake City metro area accounted for 54%.[4]
- **Relative Earthquake Risk:** In a 2008 FEMA study, Utah ranked 6th in the Nation in relative earthquake risk in terms of probabilistic Annual[ized] Earthquake Loss (AEL). The AEL for Utah (in 2008 dollars) was $89.5 million. The AEL for the Salt Lake City metro area was $52.3 million, ranking it 11th among 43 metro areas in the U.S. with an AEL greater than $10 million.[5]

# The Wasatch Fault

More than 130 years ago, the renowned geologist G.K. Gilbert wrote a classic letter to the *Salt Lake Daily Tribune*[6] warning local residents that fault scarps along the western base of the Wasatch Range (along what we now call the Wasatch fault) were evidence that large surface-faulting earthquakes had occurred before Mormon settlement in 1847 and more would occur in the future.

The Wasatch fault is Utah's longest and most geologically active fault, extending 220 miles (350 km) straight-line distance from Fayette in central Utah to near Malad City, Idaho (Figure 2).[7] The fault plane is inclined ("dips") to the west and the rock mass above the fault slips downward in a "normal" direction (see Figure 3). Over millions of years, incremental movement on the Wasatch fault in large surface-faulting earthquakes has produced valleys on the western (down-dropped) side of the fault and a prominent west-facing topographic escarpment on the eastern (uplifted) side, which early explorers called "the Wasatch Front."

The Wasatch fault is the most studied active normal fault in the world. Based on decades of detailed field studies and trenching excavations across the fault since the late 1970s, geologists have compiled abundant data on the timing and size of prehistoric ("paleo") earthquakes large enough to rupture the ground surface during the past 18,000 years or so. The depth of surficial deposits exposed in most of the trenching excavations limits the completeness of the paleo-earthquake record along the Wasatch fault to about the past 6,000 years.

Paleo-earthquake studies of the Wasatch fault have yielded key information about the fault's behavior. Rather than generating a broad range of earthquake sizes, the Wasatch fault episodically releases accumulated strain energy in similar-size or "characteristic" surface-faulting earthquakes of about magnitude 7 (for shorthand, "Big Ones").

The Wasatch fault consists of ten distinct segments (Figure 2), each of which is thought to rupture independently as a separate source of Big Ones.

**The most active parts of the Wasatch fault are its five central segments between Brigham City and Nephi. The Scenario in this report is for a Big One on the Salt Lake City segment**

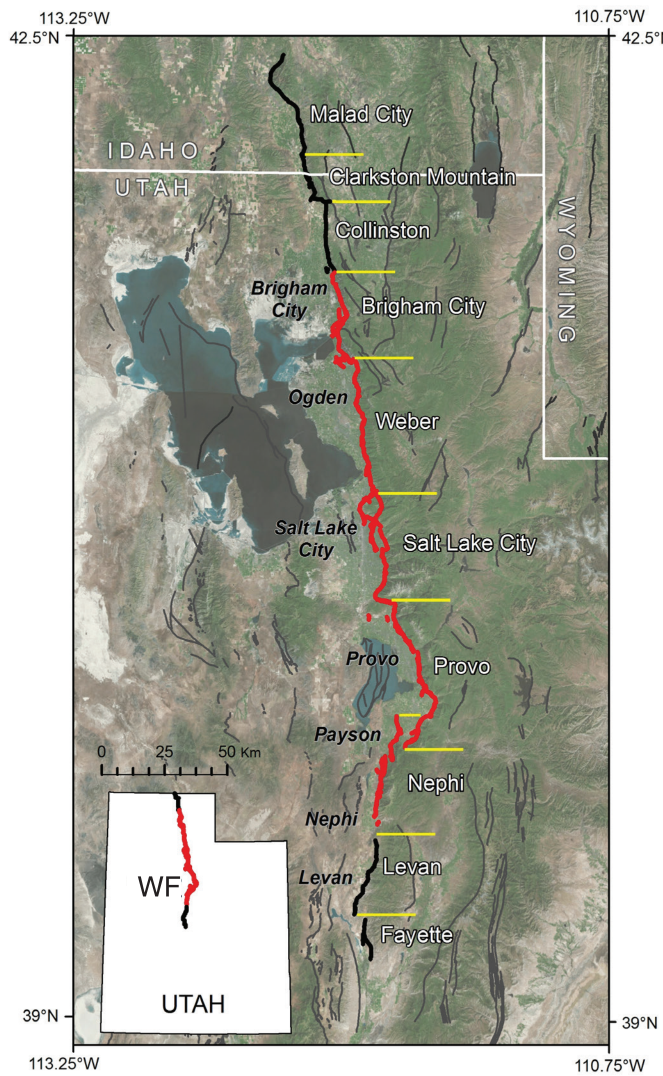
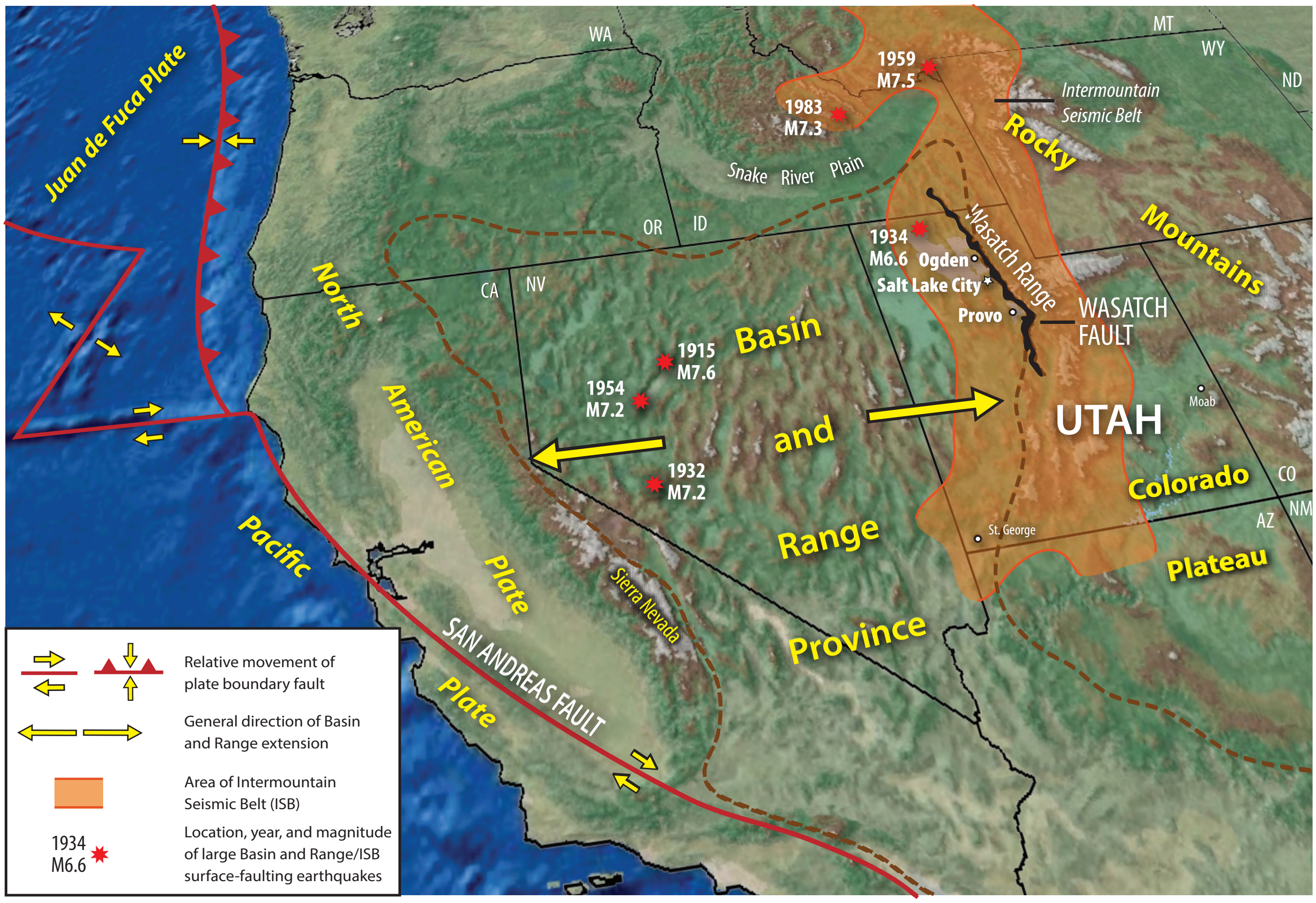



*Figure 2. The Wasatch fault, divided into its ten recognized segments (separated by yellow lines and labeled to the right). The five central segments of the fault, shown in red, are the most active. The less active end segments of the fault are shown in black (figure courtesy of the Utah Geological Survey).*




## Utah and the Intermountain West are Seismically Active

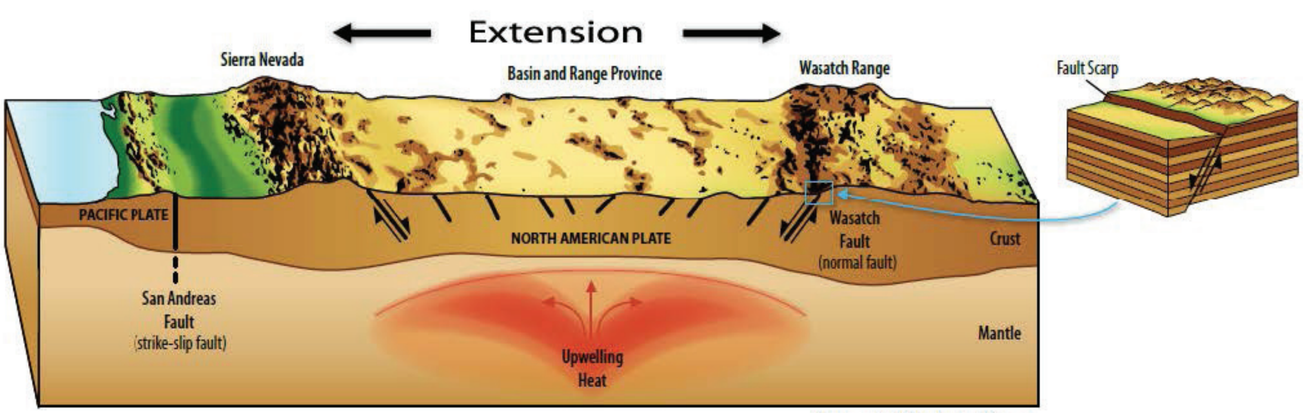



*Figure 3. Schematic map (above) and cross-section (below) of the western United States showing the tectonic setting of the Wasatch fault.[8] Stretching, or horizontal extension, of the crust produces a type of dipping (or inclined) fault called a "normal" fault in which the block above the fault moves downward.[9] The Wasatch fault is the dominant active normal fault along the eastern margin of the Basin and Range Province. Note: Some of the magnitudes indicated on the map above are surface-wave magnitudes which are typically higher than moment magnitudes ($M_W$) cited elsewhere in this report.*

## Large Prehistoric (pre-1847) Earthquakes on the Wasatch Fault

At least 22 large surface-faulting earthquakes have occurred on the central segments of the Wasatch fault during the past ~6,000 years (Figure 4). On average, one of these Big Ones has occurred about once every 300 years somewhere on one of the central segments of the fault. The pattern of large earthquakes shown on Figure 4 is not simple or regular. The inter-event times on the individual segments range from 700 to 2,700 years. The average inter-event time for individual segments ranges from 900 to 1,500 years. The Brigham City and Salt Lake City segments have the longest elapsed times since their most recent earthquakes (Figure 4), which leads to higher earthquake hazard on these two segments compared to the rest of the fault.[10] The most recent Big One on the Wasatch fault occurred on the Nephi segment about two to three hundred years ago (approximately 1740 AD).

## The Salt Lake City Segment[11]

The Salt Lake City (SLC) segment of the Wasatch fault is 25 miles (40 km) long, extending along the eastern side of the Salt Lake Valley from southeast of Draper to North Salt Lake, as shown on Figure 5(a). Active fault traces shown on the figure indicate a complex fault system in the Salt Lake Valley, including subsections of the SLC segment along the eastern side of the valley and faults of the West Valley fault zone, which extends 10 miles (16 km) north of Taylorsville in the north-central part of Salt Lake Valley. The SLC segment has three subsections, all inclined or dipping to the west: (1) the range-bounding Cottonwood fault, running from east of Draper to about Holladay; (2) the East Bench fault, trending away from the range front northwest of Holladay; and (3) the Warm Springs fault, at the northern end of Salt Lake City. The West Valley fault zone is secondary to and dips eastward towards the master Wasatch fault. Based on available data, the West Valley fault zone ruptures at the same time as, or shortly after, Big Ones on the SLC segment. Separate rupture of the West Valley fault zone would generate an earthquake of about magnitude 6.

Other key facts about the SLC segment:

- The various strands of the SLC segment dip to the west about 30°–70° (measured from the horizontal), which means that the Wasatch fault at depth lies directly beneath the urbanized Salt Lake Valley.
- At least nine large surface-faulting earthquakes have ruptured all or part of the SLC segment since about 18,000 years ago, at least eight since 14,000 years ago, and at least four since about 6,000 years ago.
- For the past 6,000 years, the average repeat time of Big Ones on the SLC segment is about 1,300 years; for the past 14,000 years, it is about 1,500 years. The most recent large earthquake on the SLC segment occurred about 1,400 years ago.[12]
- Vertical offsets of the ground surface during past Big Ones on the SLC segment, as measured in various trench excavations, have reached a little more than 8 feet (2.5 meters) and generally are in the range of 3–7 feet (1–2 meters).
- The characteristic magnitude estimated for Big Ones on the SLC segment is moment magnitude 7.1 ± 0.2.[13] The magnitude 7.0 earthquake used in this scenario is not the worst-case size.

**The average repeat time of Big Ones on the SLC segment is about 1,300-1,500 years. The last one occurred around 1,400 years ago—enough time for strain energy to build up to unleash another (the time interval between some past Big Ones on the SLC segment has been in the range of 800 to 1,200 years).**

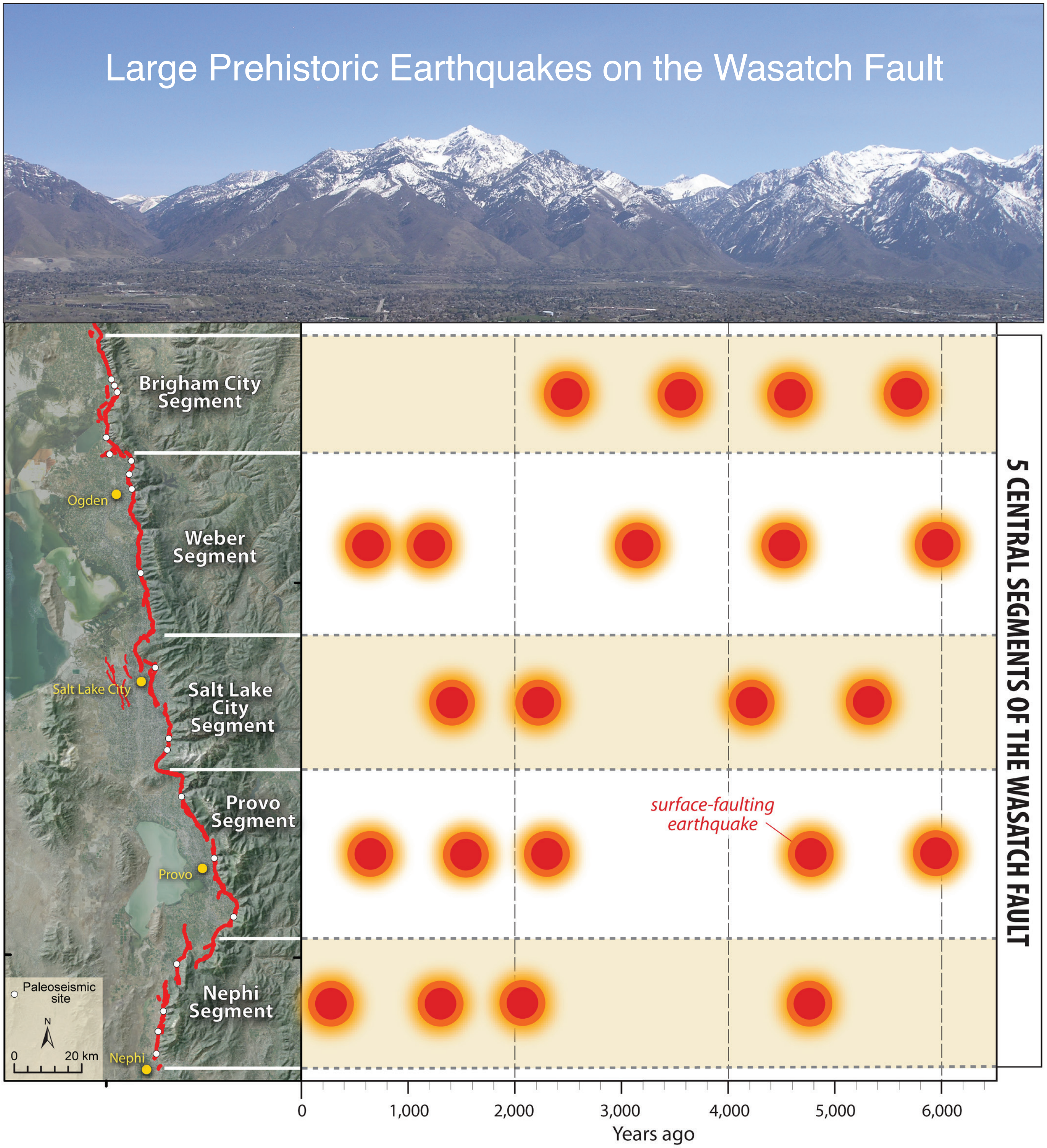



*Figure 4. Schematic plot showing the timing of large prehistoric earthquakes on the Wasatch fault (elements of the figure provided by the Utah Geological Survey).*

At least 22 large earthquakes have ruptured the central segments of the Wasatch fault since about 6,000 years ago.

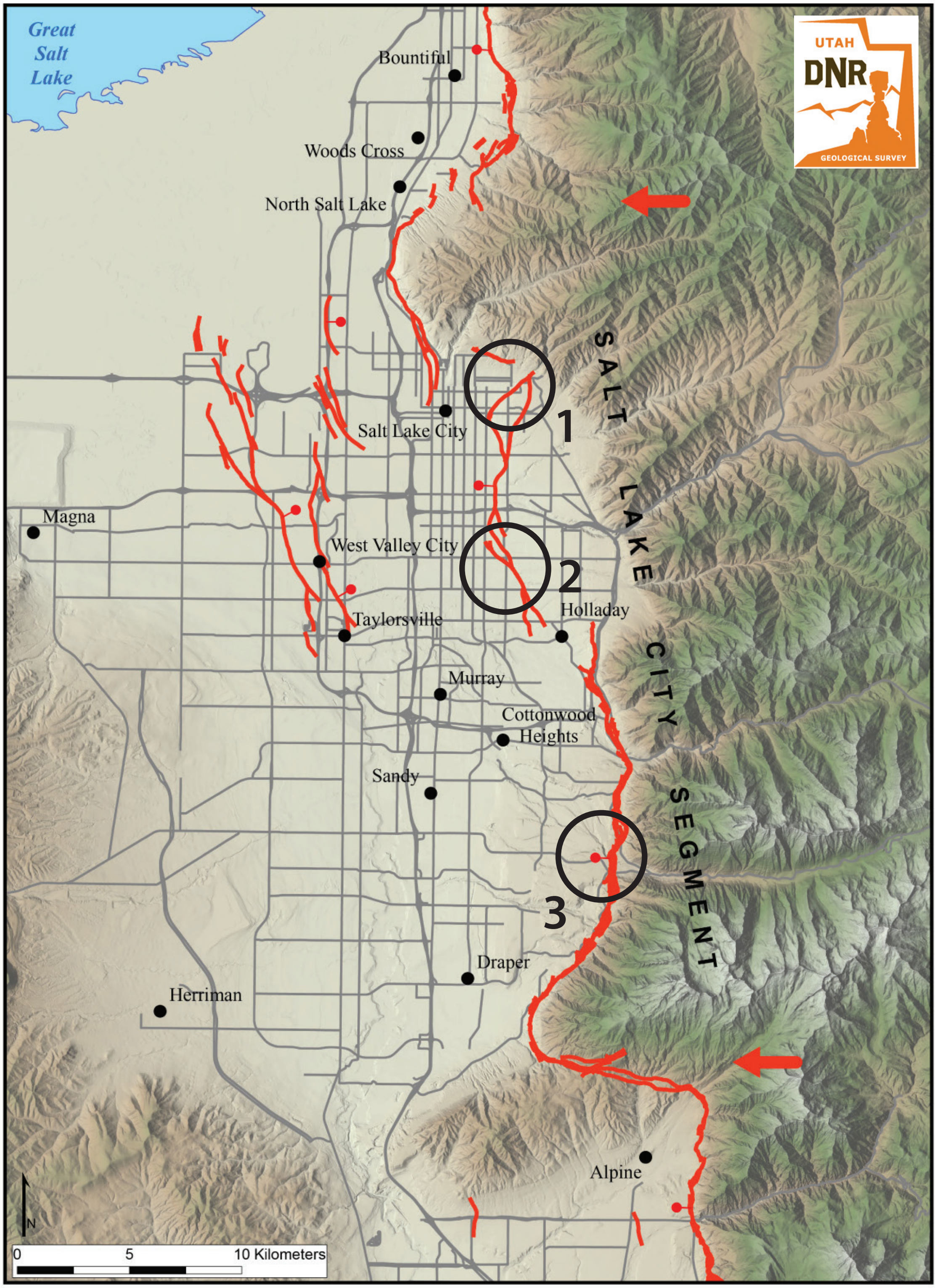



*Figure 5(a). Map of the Salt Lake City segment of the Wasatch fault and the West Valley fault zone (courtesy of the Utah Geological Survey). Bold red arrows mark the segment boundaries and red lines show the surface traces of active faults forming a complex fault system in the Salt Lake Valley. Locations of features illustrated in Figure 5(b) are shown by the numbered circles.*

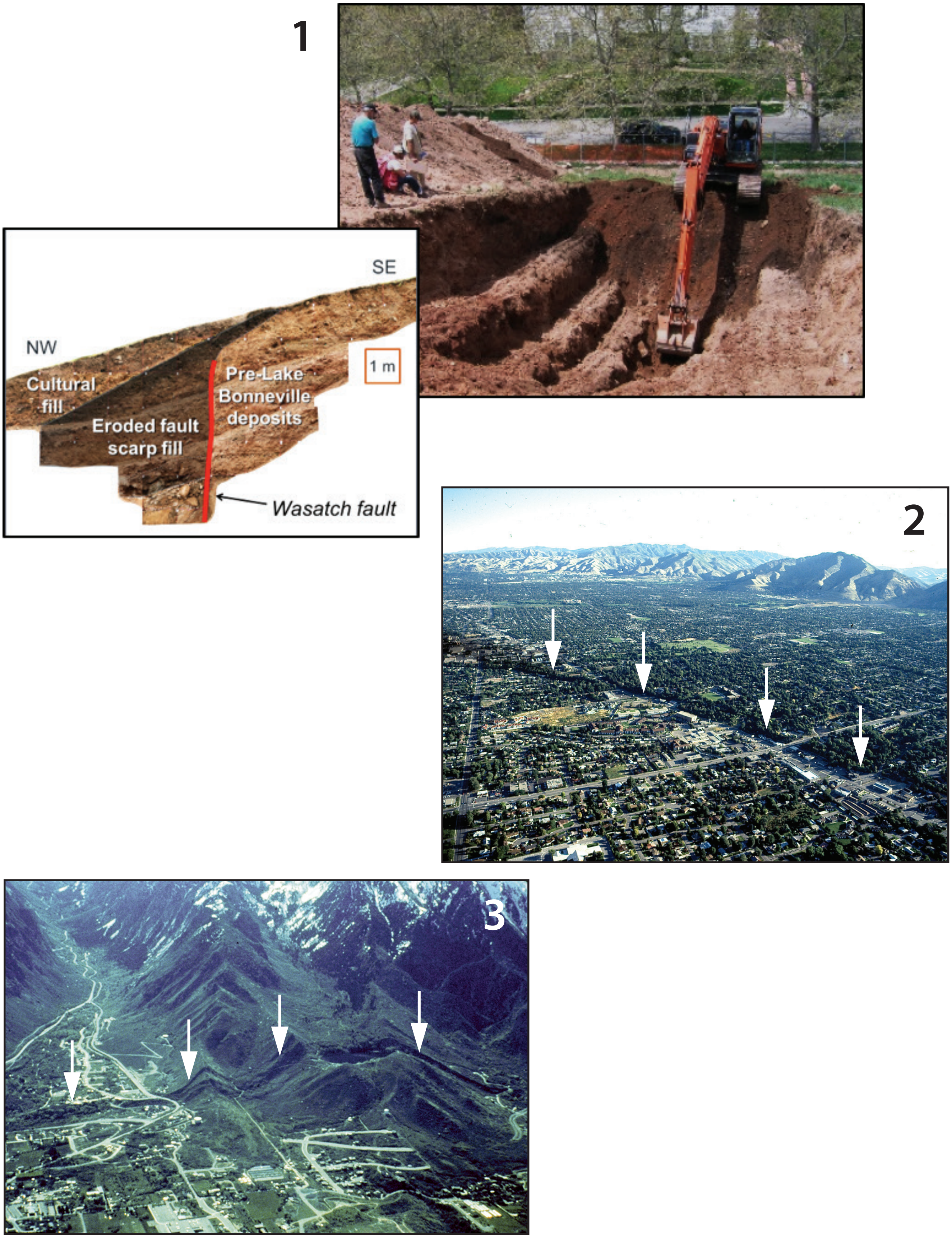



*Figure 5(b). Illustrated features, keyed to Figure 5(a), of the Salt Lake City (SLC) segment of the Wasatch fault: (1) Example trench excavation and fault exposure (inset) at Penrose Drive (courtesy of Chris DuRoss, U.S. Geological Survey). (2) Aerial photo view to the northeast along Highland Drive near 3900 South showing a subsection of the SLC segment in a densely populated area away from the mountain front (photo credit: Rod Millar). (3) Aerial photo view to the east at the mouth of Little Cottonwood Canyon (courtesy of the Utah Geological Survey). White arrows in (2) and (3) mark the surface trace of the fault.*

# Fault Rupture Scenario

The U.S. Geological Survey's ShakeMap computer program is used to predict ground motions from a magnitude ($M_W$) 7.0 earthquake along the Salt Lake City segment of the Wasatch fault (Figure 6). The magnitude is consistent with rupture of the entire segment length from Draper to southern Davis County. In predicting the ground motions, we use a fault dipping 60 degrees from the current surface trace to a depth of about 9 miles (15 km). The ground motions are calculated using a recently determined ground motion prediction equation for normal faulting earthquakes,[14] which combines magnitude, distance from the fault plane, and local soils to determine estimates of ground shaking. This ShakeMap scenario was originally developed for the 2012 Utah ShakeOut and has been used extensively by the State of Utah and FEMA for earthquake exercises and as the foundation for other planning reports such as the Wasatch Range Catastrophic Earthquake Response Plan (FEMA).

While the exact ground motions at any specific location for any particular earthquake cannot be predicted, this scenario provides a reasonable approximation of the overall scale of expected ground motions from a magnitude 7.0 earthquake on the Salt Lake City segment. The entire Salt Lake Valley and surrounding areas will experience strong to severe shaking as the result of a Salt Lake City segment rupture. The geographical distribution of these ground motions may vary from this scenario as a result of un-modeled fault rupture dynamics and unaccounted for site amplification effects due to both the local soil structure and basin reflected seismic waves,[15] but these details will not change the degree of shaking expected from this earthquake.

This scenario only models ground motions for the main shock. In the 30 days following a magnitude 7.0 earthquake, based on a reasonable aftershock model, we can expect up to three aftershocks greater than magnitude 6, 13 greater than magnitude 5, and 77 greater than magnitude 4. These earthquakes may not be as strong as the main event, but the larger aftershocks are capable of significant damage on their own, and all aftershocks may further weaken damaged structures. The aftershocks will also slow rescue and recovery efforts and likely heighten public panic. While this is a known consequence, the structural, economic, and life-safety effects have not been calculated in this scenario.

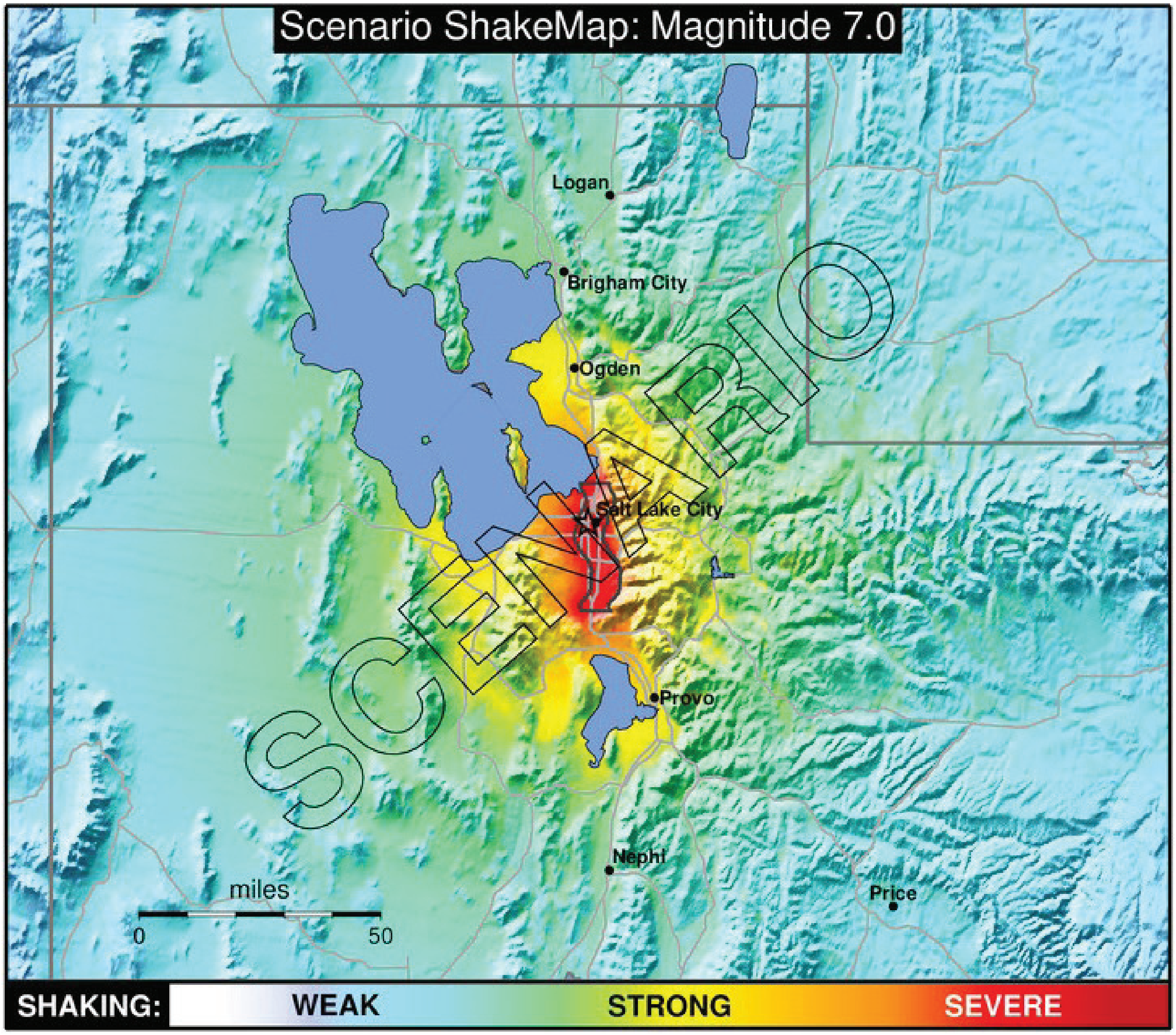
### Magnitude or Intensity?

Magnitude is a measure of the energy released in an earthquake—a single value that depends on the area of fault rupture and amount of slip. For example, the 1934 Hansel Valley, Utah earthquake had a magnitude of 6.6. The largest expected earthquakes in Utah are magnitude 7.0-7.5.

Intensity is a measure of the strength of ground shaking at a particular place, and varies by location, proximity to the source of the earthquake, and type of material underlying the site. The intensity scale ranges from low (I) to high (XII). Near the epicenter of the Hansel Valley earthquake, the intensity reached VIII; however, in Salt Lake City, intensity levels were about VI.

The intensity of shaking that a building or structure will experience during an earthquake is highly variable, but generally depends on three main factors:

- The magnitude of the earthquake—in general, the larger the earthquake, the stronger the shaking and the larger the area affected.
- The distance from the earthquake—the closer to the source of the earthquake, the greater the shaking.
- The type of ground material beneath the structure—soils may amplify or deamplify the shaking relative to bedrock.




| PERCEIVED SHAKING | Not felt | Weak | Light | Moderate | Strong | Very strong | Severe | Violent | Extreme |
|---|---|---|---|---|---|---|---|---|---|
| POTENTIAL DAMAGE | none | none | none | Very light | Light | Moderate | Mod./Heavy | Heavy | Very Heavy |
| PEAK ACC.(%g) | <0.1 | 0.5 | 2.4 | 6.7 | 13 | 24 | 44 | 83 | >156 |
| PEAK VEL.(cm/s) | <0.07 | 0.4 | 1.9 | 5.8 | 11 | 22 | 43 | 83 | >160 |
| INSTRUMENTAL INTENSITY | I | II–III | IV | V | VI | VII | VIII | IX | X+ |

Scale based upon Wald, et al.; 1999

*Figure 6. SkakeMap Scenario for a magnitude 7.0 earthquake on the SLC segment. Severe shaking corresponds to peak ground velocities greater than 80 cm/sec. Most of the Salt Lake Valley will experience peak ground velocities greater than 40 cm/sec. The maximum intensity from this earthquake is IX, which corresponds to violent shaking and the potential for heavy damage.*

All loss estimates presented later in this report are based on shaking from the scenario earthquake only.

# Earthquake-Generated Ground Failure

Most earthquake damage comes from ground shaking, but other effects can be just as devastating. Ground failure poses a significant hazard following earthquakes along the Wasatch Front. In the 1992 M 5.8 St. George, Utah earthquake, a massive landslide in Springdale caused the most damage to houses.

Four types of ground failure will occur during the scenario earthquake:

1. Surface fault rupture
2. Liquefaction
3. Landslides
4. Ground subsidence

## Surface Fault Rupture

Fault rupture of the Salt Lake City segment of the Wasatch fault will cause the ground to rupture as much as eight feet vertically and up to three feet of horizontal extension. This much movement is likely to tear apart buildings, pavement, pipelines and anything built across the fault.

The rupture will be similar to that observed following the 1983 $M_W$ 6.9 Borah Peak, Idaho earthquake.[16] That faulting occurred primarily on the Lost River fault between Mackay and Challis. Figure 7 shows a section of the 1983 surface rupture where it traversed a hillside with a disconnected upward step; a faint trace of an antithetic fault rupture is visible to the left of the main fault. Figure 8 is a view of the fault rupture where it crossed Doublespring Pass Road. The Borah Peak fault rupture at Doublespring Pass Road disrupted a zone of ground that was 115 feet (35 m) wide with observed net down dip displacement of about nine feet. Based on this similarity, surface fault ruptures for the scenario earthquake would occur within zones about 100 feet or wider that would irregularly follow mapped traces of the Wasatch fault. Earthquake damage would be intense within these zones. A diagram of ground displacements such as occurred in Idaho and is likely along the Wasatch fault, is reproduced in Figure 9.

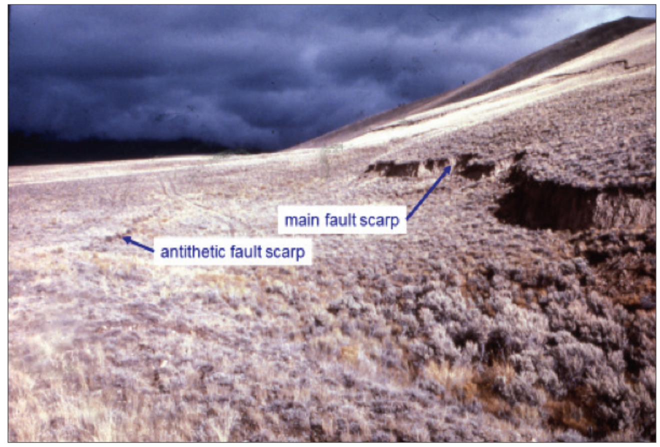



*Figure 7. View of part of fault rupture generated by the October 28, 1983 Borah Peak, Idaho earthquake. Photo by T.L. Youd.*

*Figure 8. View of Borah Peak Idaho surface faulting where it crosses Doublespring Pass Road. Photo by T.L. Youd.*

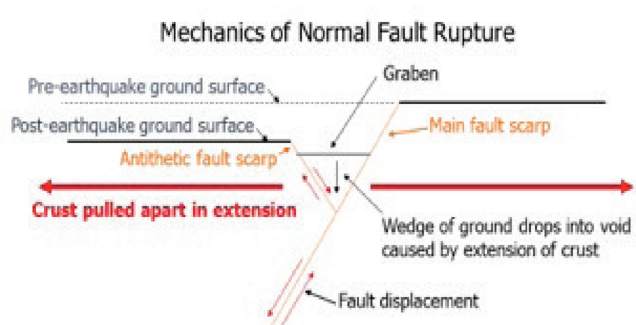



*Figure 9. Diagram of typical ground displacements associated with normal faulting such as occurred during the 1983 Borah Peak, Idaho earthquake and is expected during the Salt Lake scenario earthquake. Diagram by T.L. Youd.*

## Liquefaction

Liquefaction occurs as seismic waves propagate through loose granular sediment—silts, sands and gravels—that lie below the water table. Earthquakes tend to compact loose materials. If water within the sediment cannot easily escape, pressure builds up in the water causing the sediment to soften and weaken. When the pressure reaches a critical level, the sediment temporarily looses strength and behaves as a viscous liquid, hence the term "liquefaction," the transformation of a solid into a liquid.[17] The soil may freely deform, leading to ground displacements that can tear apart structures and pipelines similar to fault displacement. With time, usually minutes to days, the excess groundwater pressure dissipates and the material re-solidifies.

Liquefiable sediments are not randomly distributed in natural landscapes, but occur only in locations where loose granular sediment has been deposited in recent geologic time. Geologic and hydrologic factors used by geologists and engineers to identify locations where liquefiable deposits are likely to lie underground include: (1) Age of deposition—the younger the sediment, the more liquefiable; (2) Depth of water table—the shallower the water table, the more liquefiable the sediment; (3) Density of sediment—the looser the sediment, the more liquefiable; (4) Soil type—the more clayey the soil, the more resistant to liquefaction.[18]

Based on the above four factors, liquefaction potential maps have been compiled for several counties in Utah. A map for Salt Lake County is reproduced in Figure 10. This map shows that areas with high liquefaction potential are confined to lowlands along the Jordan River and its tributaries and to low-lying areas between 4500 South and the Great Salt Lake. Most liquefaction effects generated by the scenario earthquake will occur in these lowland areas.

Areas of moderate to low liquefaction potential occur on the map as bands up to five miles wide bordering the high-potential zone. Not all the areas characterized by high liquefaction potential will develop liquefaction effects. Many areas of high liquefaction potential are likely underlain by non-liquefiable clay-rich soils; drilling and testing is necessary to identify areas that are actually underlain by significant layers of liquefiable sediment. Four ground-failure types commonly develop as a consequence of liquefaction: lateral spread; ground oscillation; loss of bearing capacity; and sand boils and ground settlement.[20]

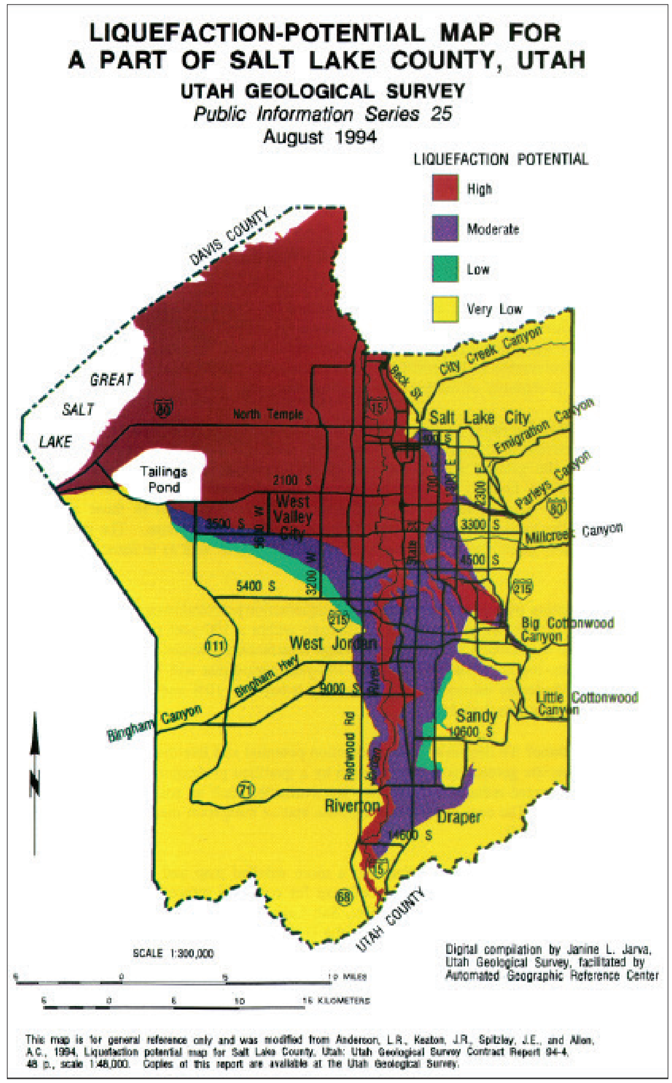



Figure 10. Liquefaction-potential map for a part of Salt Lake County, Utah.[19]

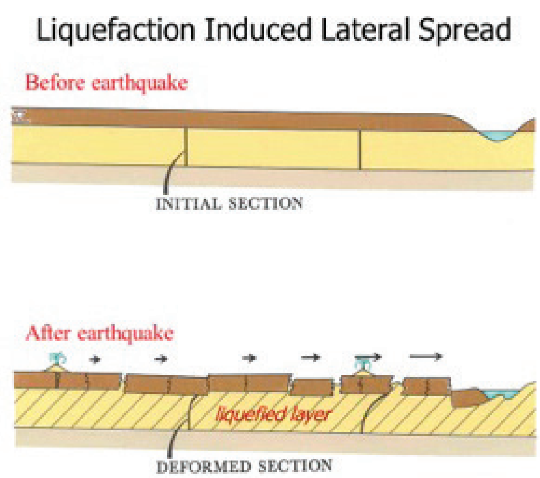



Figure 11. Before and after diagrams of liquefaction-induced lateral spread.[21]

### *Lateral Spread*

Lateral spread is the most damaging effect of liquefaction (Figure 11). For example, liquefaction during the 1964 Alaska earthquake affected more than 250 highway and railway bridges at river crossings, damaging most beyond repair, with many collapsing (Figure 12). The bridge damage disrupted transportation facilities for months while repairs were made. This disruption wreaked havoc on emergency response and short-term business activity. Lateral spreading also pulled apart many buildings in Anchorage and Valdez, Alaska, in Niigata, Japan, and in many other earthquakes, causing severe to irreparable damage to many structures (Figure 13). This in turn led to drastic economic losses and disruptions to local economies. Damage to pipelines from lateral spreading has severely disrupted water, gas, and sewage systems during many earthquakes (Figure 14).

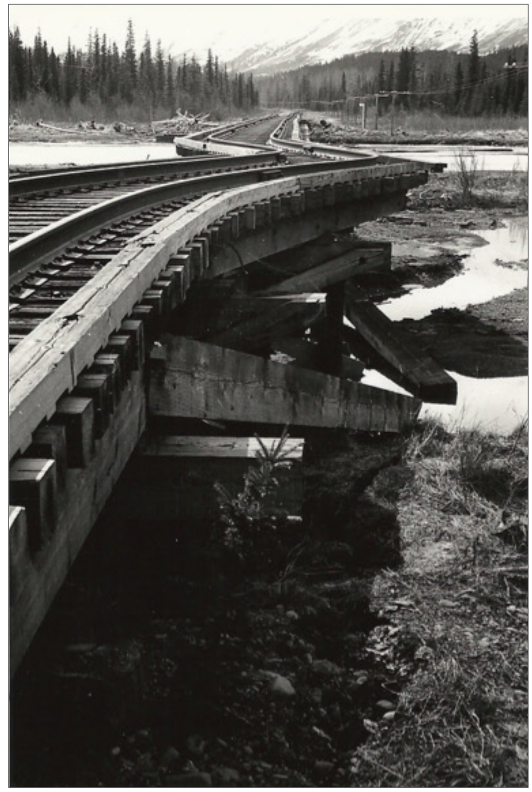


*Figure 12. View of railroad bridge compressed by liquefaction-induced lateral spread during the March 23, 1964 Alaska earthquake. Photo courtesy of the U.S. Geological Survey.*

### *Ground Oscillation*

Ground oscillation occurs on flat ground where there is too little gravitational pull to cause lateral spread, but where earthquake-generated inertial forces can cause upper layers of the ground to oscillate back and forth in waves over a subsurface weakened layer (Figure 15). Most ground oscillation damage has been to pavement and pipelines.

### *Loss of Bearing Capacity*

Liquefaction beneath heavy buildings and other heavy structures often allows them to sink into what used to be solid ground, and tip or settle at an angle when the ground re-solidifies (Figure 16). Such foundation failures (Figure 17) usually damage a building's functionality, leading to expensive repairs or the demolition of the building entirely. Liquefaction may also cause buried structures, such as tanks, pipes, and manholes, to float upward (Figure 18).

*Figure 13. View of interior of building pulled apart by liquefaction-induced lateral spread at San Fernando Juvenile Hall during the 1971 San Fernando, California earthquake. Photo by T.L. Youd.*

### *Sand Boils and Ground Settlement*

Liquefaction often leads to ejection of ground water laden with sediment creating miniature sand volcanoes or sand boils (Figure 19). Sand boils by themselves are usually not destructive, but the ejected water and sediment may cause local flooding and bothersome deposition of sediment on the ground surface adding to other debris. Such effects are prime indicators that liquefaction has occurred at depth. The eruption of sand boils is usually accompanied by

*Figure 14. View of water pipeline rupture due to liquefaction-induced lateral spread near the San Fernando Juvenile Hall during the 1971 San Fernando, California earthquake. Photo by T.L. Youd.*

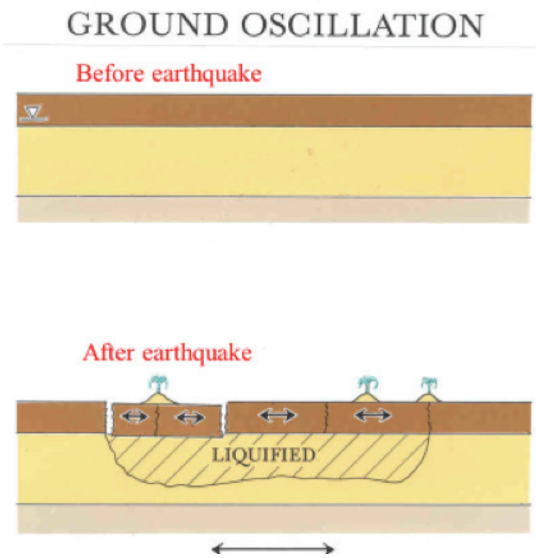



*Figure 15. Before and after diagrams of liquefaction-induced ground oscillation.[22]*

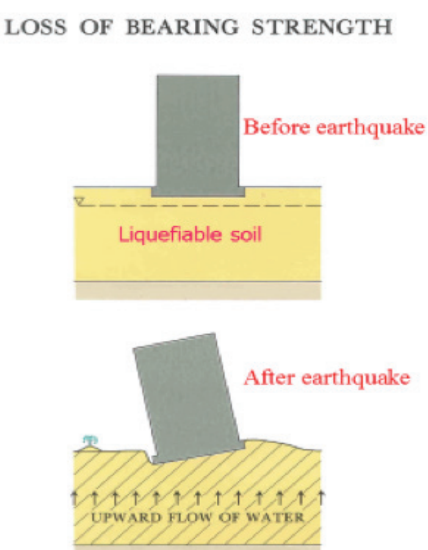



*Figure 16. Before and after diagrams of liquefaction-induced bearing capacity failure.[23]*

*Figure 17. Building in Adapazari, Turkey that tipped over due loss of bearing capacity during the 1999 Kocaeli, Turkey earthquake. Photo by T.L. Youd.*

*Figure 18. Buried oil storage tank at an industrial facility that floated to ground surface due to liquefaction of subsurface soils during the 1993 Hokkaido-nansei-oki, Japan earthquake.[24]*


*Figure 19. View of sand boil generated by liquefaction during the 2010 $M_W$ 4.6 Randolph, Utah earthquake. Photo courtesy of Chris DuRoss, Utah Geological Survey.*

ground settlement to compensate for compaction of the liquefiable layer and the volume of sediment and water ejected. Ground settlements have been damaging to building foundations that may fracture or tilt unevenly and to pipelines that may rupture due to the increased strain on the pipe. Uneven settlement may cause sewer lines to lose gradient, which impedes flow and may cause local flooding with contaminated water.

## Landslides

Earthquakes are a major cause of landslides, and a magnitude 7 earthquake may cause hundreds of landslides over a large area around the epicenter. Many types of landslides may occur, varying greatly in size, amount of displacement, and damage potential. Earthquake-induced landslides will occur in both soil and rock.

Landslide hazards are not randomly distributed throughout the region, but vary as a function of slope steepness, rock material, and groundwater conditions. Landslides are much more likely during wet periods such as spring snowmelt or following prolonged rainfall. Landslide maps for the Wasatch Front scenario earthquake for both wet (Figure 20) and dry conditions (Figure 21) have been compiled. The maps clearly show the difference in hazard between wet and dry conditions. The maps also show that the hazard is greatest in areas with steep topography.

A simplified diagram of the more common types of landslides is shown in Figure 22. Rock falls and soil and rock slides are most common.[28] The scenario earthquake would likely cause all types of landslides near the epicenter, but the size, number, and amounts of displacement drop off quickly away from

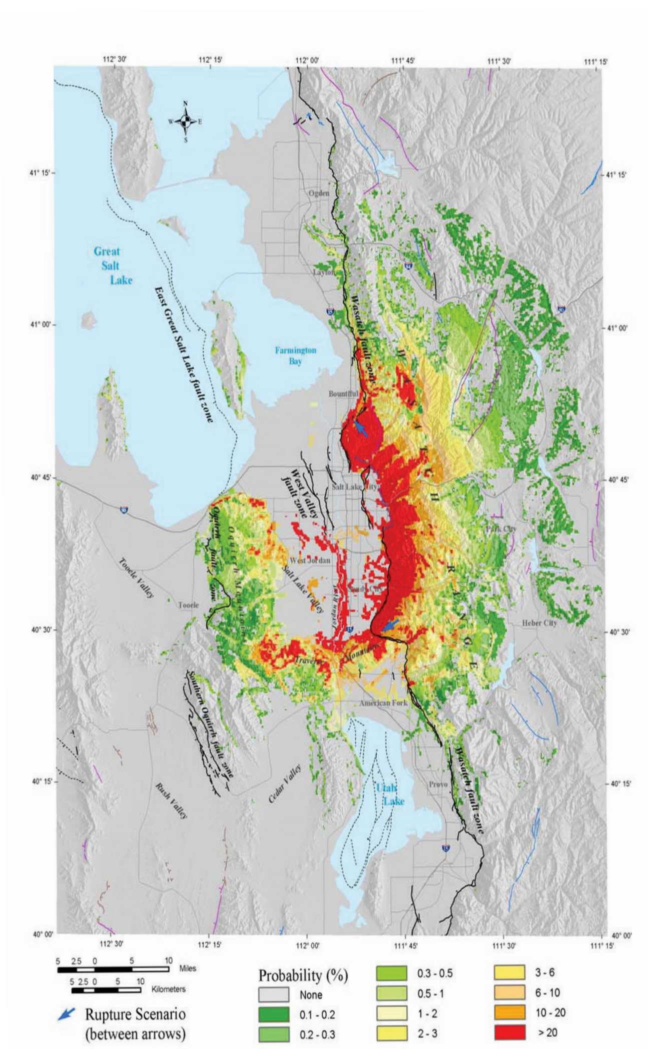



Figure 20. Landslide probability under wet conditions.[25]

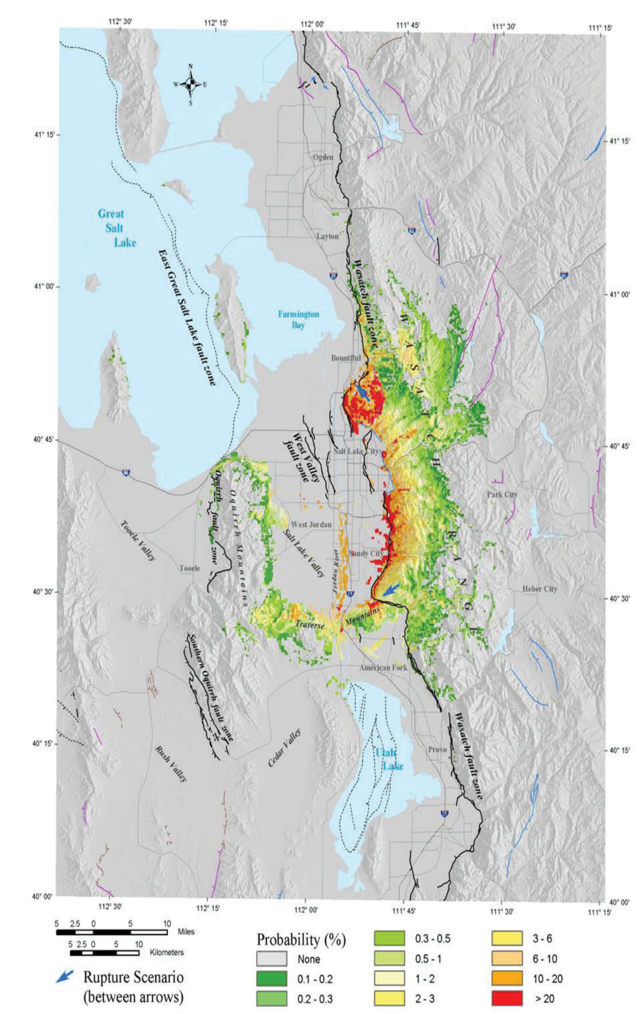



Figure 21. Landslide probability under dry conditions.[26]

the epicenter. Landslide and landslide-hazard maps exist for parts of Utah and the Wasatch Front. These maps indicate where unstable slopes exist and where future landslides are most likely.

### Rock Falls

Rock falls consist of individual boulders or shallow disrupted rock masses that bounce, roll, or free-fall down slopes.[29] They are the most common type of landslide caused by earthquakes, and may occur in both the mainshock and aftershocks greater than magnitude 4.[30] Damages are rare in the steep hillside source areas of rock falls, where few structures exist, but typically structures have been built at the base of these slopes in the rock-fall runout zone. In a mountainous area such as the Wasatch Front, hundreds of rock falls can be expected from hillsides along the upper east benches and throughout the Wasatch Range. In the 1983 $M_W$ 6.9 Borah Peak, Idaho earthquake, large dust clouds from rock falls were reported throughout the Lost River Range. Similar dust clouds were seen in the 1988 $M_L$ 5.2 San Rafael Swell earthquake in central Utah (Figure 23).

### Soil and Rock Slides

Soil and rock slides are typically shallow disrupted translational movements of fragments or blocks on a basal slide surface, often a bedding plane or weak layer that lacks lateral support and is exposed in a hillside. Shallow, more coherent rotational slides occur but are less common. Soil and rock slides may cause moderate to severe damage to structures depending on the amount of displacement. Prehistoric slides exist throughout the Wasatch Front that have variable vulnerability to reactivation by earthquake ground shaking. Earthquake-induced slides may occur in the mountains, as well as in more populated areas of the basin, particularly in soil slopes in steep bluffs bordering rivers (for example, the Jordan River, Little and Big Cottonwood Creeks, Parleys Creek, Weber River). Historically, one of the largest earthquake-induced rock slides in Utah was the Springdale landslide in the 1992 M 5.8 St. George earthquake. It was a large, coherent, deep-seated slide with both translational and rotational components that moved about 33 feet (10 m).[31] The only three homes that had been built on the surface of the landslide were destroyed (Figure 24), and damages would have been far greater if the subdivision had been completed.

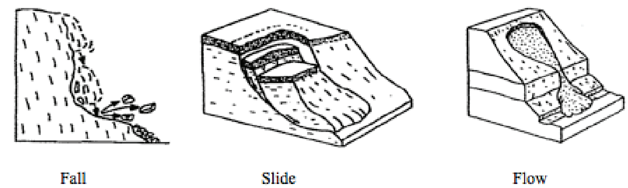



*Figure 22. Three main landslide types in soil and rock.[27]*

*Figure 23. Dust clouds from rock falls in the 1988 $M_L$ 5.2 San Rafael Swell earthquake.*

*Figure 24. Damage to a home caused by the Springdale landslide in the 1992 M 5.8 St. George earthquake.*

### *Rock Avalanches*

Rock avalanches are rapid, large disrupted slides that typically involve flow mechanisms in the runout zone and generally occur only as a result of strong ground shaking in large earthquakes.[32] They may be spectacular failures that obliterate anything in their paths and are often accompanied by damaging air blasts around their peripheries. Although generally uncommon even in large earthquakes, an important historical rock avalanche in the Intermountain region was the Madison landslide (Figure 25) accompanying the 1959 $M_W$ 7.3 Hebgen Lake earthquake in Montana. Several similar large prehistoric rock-avalanche deposits have been mapped along the Wasatch Front at the base of the Wasatch Range, although we do not know if they were caused by large, prehistoric earthquakes.

## Ground Subsidence

Ground subsidence is the permanent lowering of the ground surface as a result of surface faulting. The scenario indicates possible permanent ground subsidence in the area west of the Salt Lake City segment of the Wasatch fault. Incursion of surface water along the east shore of Great Salt Lake and up the Jordan River could cause local flooding and a rise in the ground-water table.

Possible flooding by Great Salt Lake depends on the amount of displacement on the fault, but also the level of the lake at the time of the earthquake. At higher lake levels, waters will inundate the Jordan River flood plain upstream from where the river enters Farmington Bay. At the maximum historical lake elevation of 4,212 feet (1,284 m), water could flood approximately 3 miles (4.8 km) southward along the flood plain.

Although flood-control dikes protect much of the area, dike failure or ground-water underflow beneath them or infiltration through them may result in flooding of oil refineries, a sewage disposal facility, and residential and commercial development in rapidly growing areas northwest of Salt Lake City.[33] At high lake levels, floodwaters would reach the northern part of Salt Lake City International Airport and could approach Interstate Highway 15.

*Figure 25. Damming of the Madison River by the Madison landslide in the 1959 $M_W$ 7.3 Hebgen Lake earthquake formed Quake Lake. Photo courtesy of the U.S. Geological Survey.*

# Loss Modeling Using Hazus

Hazus is a natural hazards loss estimation software package developed by the Federal Emergency Management Agency and the National Institute of Building Sciences. It is used to model economic, life, building, and lifeline losses and to model shelter, debris removal, and essential service needs following: earthquakes, flooding, hurricanes, and coastal surges. Its primary purpose is to provide a methodology and needed software to predict losses at a regional scale. These loss estimates are used by local, state, and regional offices to plan and stimulate efforts to reduce risks and to prepare for emergency response and recovery. Loss estimates are also generated post-disaster to evaluate the severity of loss and to identify needed resources.

Developed at a national level, the program includes many default databases for general building stock—construction type and occupancy classes—and facility information for select lifeline and essential facilities. The program also contains default databases for fault structures and ways to predict ground motion.

While the default information is useful for gauging the potential impact, user-supplied regional specific information is necessary to improve the accuracy of the loss estimation. The more complete and accurate the regional specific information used in the calculations, the more accurate the resulting loss estimations.

Unfortunately, gaining access to regional specific information from businesses, as well as government sources is not straightforward. The table below shows the input for the Hazus run used in this scenario. Importantly, losses for several critical facilities and structures, such as schools, electric and natural gas facilities, and water facilities are based on the Hazus defaults. Because of this, the scenario is most likely under-estimating the severity of overall losses, especially those related to schools. As additional information for the Wasatch Front and the State of Utah becomes available, the estimated losses will change, likely making the losses greater.

## Hazus Data Inputs

| Local/Regional Specific Information | Default/National Based Information |
|---|---|
| • Salt Lake County Assessor database (2009)<br>• Residential building counts and building area (2010)<br>• Updated unreinforced masonry building distribution for all of Utah<br>• Utah Division of Emergency Management (DEM) Federal Emergency Management Agency (FEMA) custom updates<br>- Hospitals (2012)<br>- Highway bridges from UDOT (2012)<br>- Light rail stations and segments (2012)<br>• Geologic data<br>- Liquefaction and landslide susceptibility<br>- Soil type and water depth<br>• Input ground motions (see pages 15-16)<br>• *RSMeans*® construction estimations (2012) | • Homeland Security infrastructure data (2011/2012)<br>- Fire stations<br>- Police stations<br>- Emergency Operation Centers<br>- Natural gas pipelines<br>- Oil pipelines<br>• Hazus default database<br>- Schools - Rail segments<br>- Dams - Airport runways<br>- Airports - Communication facilities<br>- Oil facilities - Electric power facilities<br>- Bus facilities - Natural gas facilities<br>- Rail facilities - Hazardous material facilities<br>- Rail bridges - Waste water facilities<br>- Rail segments |

# Loss Estimations[34]

## Economic Impact

The earthquake loss estimates provided in this report are based on a region that encompasses Utah's 12 most northern counties: Box Elder, Cache, Davis, Juab, Morgan, Rich, Salt Lake, Summit, Tooele, Utah, Wasatch, and Weber.

The region comprises 27,583 square miles. There are more than 751,000 households in the region; its total population is just under 2.4 million based on the 2010 U.S. Census. There are an estimated 757,000 buildings in the region, with a total building replacement value (excluding contents) of just under $156 billion. Approximately 92 percent of the buildings and 66 percent of the building value are residential.

The modeled losses from this scenario event are severe (see table on following page). This includes (1) direct building-related capital losses (including structural, non-structural, content, and inventory) of $24.9 billion, (2) income losses of $6.9 billion, and (3) lifeline-related losses of $1.4 billion. Lifeline-related losses for this scenario are primarily based on default data.

An estimated 84,400 households will be displaced with 52,700 individuals seeking shelters. Depending on the time of day, there will be an estimated 2,000 to 2,500 deaths. An estimated 7,400 to 9,300 people will be injured and need hospital care. The number of available hospital beds will be reduced from 4,790 to 3,200.

Essential lifelines such as water, electricity, gas, and sewer will be disrupted for days to months and in some locations in the Salt Lake Valley, perhaps longer. To evaluate nearly 308,100 structures in 30 days, it will take about 2,400 building inspectors to complete the task. Large amounts of debris are expected in the aftermath of the earthquake. Estimates are that nearly 21 million tons of debris will be generated by the earthquake. Of the total amount, brick and wood comprise 42% of the total with the remainder being reinforced concrete and steel. It is estimated that over 821,600 truckloads, at 25 tons per truck, will be required to remove the debris generated by the earthquake.

Much of the economic and human loss is driven by the high number of unreinforced masonry buildings. The restoration of essential services is driven by the lifelines that criss-cross throughout the region. More detailed information on both of these topics follows.

## Unreinforced Masonry (URM) Buildings

URMs represent a large source of the expected building damages in the earthquake scenario results. The more than 147,000 URMs in the study area make up about 20 percent of the total number of structures but represent a disproportionately high number of the severely damaged buildings.

*Example two-story URM residence. Photo courtesy of Barry Welliver.*

Compared to other building types, URMs are well-known to pose a greater threat to life-safety when subjected to strong ground shaking. This should give reason for concern, since URMs (although yet to be tested by a large earthquake) house large numbers of Utah residents and small businesses.

*Example one-story URM residence. Photo courtesy of Barry Welliver.*

The scenario shows that 90,200 URM buildings—over 61 percent of the total number in the 12-county area—will be moderately damaged or totally destroyed following a magnitude 7.0 earthquake. Many

# Summary of Hazus Results

## Human Impact

### Casualties

| | |
|---|---|
| Life Threatening Injuries | 7,400 - 9,300 |
| Fatalities | 2,000 - 2,500 |

### Shelter Needs

| | |
|---|---|
| Displaced Households | 84,400 |
| Individuals Seeking Temporary Shelter | 52,700 |

## Economic Impact

### Estimated Short-Term Economic Loss

| | |
|---|---|
| Building-Related | $24.9 billion |
| Income | $6.9 billion |
| Lifeline-Related | $1.4 billion |
| Total | $33.2 billion |

### Building Damage

| Damage Category | Number of Buildings Affected | Percent of 757,000 Total Buildings |
|---|---|---|
| Slight | 125,500 | 16.58% |
| Moderate | 78,400 | 10.36% |
| Extensive | 48,800 | 6.45% |
| Complete | 55,400 | 7.32% |

Hazus Building Damage Categories

| Damage Category | Immediate Post-Earthquake Inspection | Range of Possible Economic Loss Ratios | Probability of Long-Term Building Closure | Probability of Partial or Full Collapse |
|---|---|---|---|---|
| Slight | Green Tag | 0% - 5% | P = 0 | P = 0 |
| Moderate | Green Tag | 5% - 25% | P = 0 | P = 0 |
| Extensive | Yellow Tag | 25% - 100% | P ~ 0.5 | P ~ 0 |
| Complete | Red Tag | 100% | P ~ 1.0 | P > 0 |

### Critical Facility Damage

| | |
|---|---|
| Impaired† Hospitals (Acute Care) | 15 out of 32 |
| Impaired† Schools | * |
| Impaired† Police Stations | * |
| Impaired† Fire Stations | * |

† At least "moderate" damage.

## Lifelines

### Utility System Performance

| | Day 1 | Day 3 | Day 7 | Day 30 | Day 90 |
|---|---|---|---|---|---|
| Households without Potable Water | 483,600 | 466,100 | 442,800 | 362,900 | 332,800 |
| Households without Electricity | 444,600 | 251,200 | 105,900 | 27,300 | 800 |

### Transportation

| | |
|---|---|
| Impaired‡ Roads | * |
| Impaired§ Bridges | 595 out of 1,805 |

‡ At least "moderate" damage—or several inches of settlement or offset of the ground.

§ At least "moderate" damage—or column cracking or chipping, movement of the abutment, settlement of the approach, etc., but where the columns are structurally sound.

### Debris Generated

| | |
|---|---|
| Tons | 21,000,000 |
| Truckloads (25 tons/truck) | 821,600 |

* Insufficient data for Hazus calculation

others, partially damaged by the first shock, will move into this category following the many expected aftershocks. Other damaged URMs will be uninhabitable for long periods following an earthquake.

It is not difficult to see the tremendous impact this one building type will play in our recovery.

*Family at Red Butte Gardens. Image courtesy of the University of Utah*

People in URM residences will likely be barred from inhabiting their damaged homes because of the dangers of collapse. Immediately following an earthquake, all structures will need to be assessed for damage using a rapid visual screening method. Those buildings receiving a "yellow" or "red" tag will have restrictions placed upon them limiting or restricting use and occupancy. Complicating this scenario is the likelihood that inspectors—many more than currently employed in Utah—may need many days or weeks to assess the buildings and until that can happen, occupancy will be prohibited due to safety concerns.

Displaced families will require sheltering which will place urgent needs upon the communities and state. Temporary housing for those affected will most likely not be immediately available, leading to confusion and requiring self-sufficiency for a longer period of time than most will anticipate. Given Utah's harsh climate, the time of year during which the earthquake occurs could worsen these problems.

Businesses, especially small businesses, will likewise experience occupancy issues in the immediate aftermath of an earthquake. This will place tremendous stress on the area as goods and services may be unavailable for weeks or months, lengthening recovery time.

In the weeks and months following the earthquake, URM buildings will need to be evaluated and determinations made as to whether they can be repaired. Policies for retrofit and rehabilitation of these buildings will need to be established quickly, and since unreinforced masonry is a building construction type no longer allowed by building codes, those decisions will be tough. The need to get people back into permanent housing will be weighed against the safety measures needed to strengthen URMs. Indeed, the obvious poor performance of URMs may cause owners to be sufficiently concerned so as to reconsider the expenses involved and abandon their homes.

*A Utah small business. Photo courtesy of the Utah Office of Tourism*

The social, financial, and political impact of this one building type's performance in a magnitude 7 earthquake will reach deeply into the fabric of Utah's communities. Facing this reality now means we must reorient our planning and safety concerns.

## Lifeline Impact

Lifelines are the critical infrastructure that provide the services that a modern society has come to expect. Lifelines connect cities and states together. Utility lifelines provide the basic services within a community.

The vast majority of streets and roads contain utility lines. Water, sewer, and natural gas are below ground. Electric and communication lines may be above, on poles, or in buried conduits. All are, to varying degrees, susceptible to the various forms of earthquake hazards that the Salt Lake Valley will experience during a major event on the Wasatch fault.

The Hazus data presented in table form provides an estimate of the amount of failure that may occur. In this section, we will try to convey a sense of the type of damage a significant earthquake will produce along the Wasatch fault for the various types of lifelines. The primary source document we are using is *FEMA*

*224: Seismic Vulnerability and Impact of Disruption of Lifelines in the Conterminous United States.*[35]

*Conventional highway bridges* are structures with spans less than 500 feet. They may be made of concrete or steel. Typical foundations include abutments, spread footings, piles, and piers. In the Salt Lake Valley, bridges are primarily found in conjunction with the interstate highways, although smaller bridges cross the Jordan River and various canals. The most vulnerable components of bridges include support bearings, abutments, footings, and foundations. Road displacement of only several inches can make a bridge unpassable. Collapse of a bridge will also disrupt activities below the bridge. As the interstate highways in Salt Lake County have been widened and improved, bridges have also been upgraded to the seismic standards appropriate for their importance in the freeway system.

Westbound traffic on Interstate-80 near the 1300 East on-ramp in Salt Lake City. Photo courtesy of the Utah Department of Transportation

*Freeways and major highways* are designed to withstand significant traffic loading over a long period of time. Typical earthquake shaking damage may include soil failure beneath the pavement and cracking or heaving of the pavement. Lateral ground movement will cause misalignment of the road surface. Embankments may also be compromised. Even with good design practices for modern highway construction, some damage and closures can be anticipated.

*Local roads* will not fare as well as the highway system. These roads are not designed to handle traffic loads like the major highways experience. Pavement is typically thinner and subgrade materials will not be as thick. Pavement damage may include cracking, buckling, misalignment, or settling.

*Railway bridges* tend to be simpler in design than highway bridges, but share the vulnerabilities, particularly relating to foundation issues. Railroad tracks are most susceptible to settlement at embankments, with shaking alone causing little damage. However, with the growth of the FrontRunner and TRAX systems in Salt Lake County, even slight damage will impact a significant percent of the population.

Utah Transit Authority FrontRunner commuter train. Photo courtesy of the Utah Office of Tourism

*The Salt Lake City International Airport* is in a high groundwater area with the potential for liquefaction. Although airport pavements and subgrades are engineered for heavy contact loads and the requirement for level surfaces over an extended distance, some amount of disruption can be expected. Terminal buildings, control towers, hangars, parking structures, and the other miscellaneous buildings and facilities associated with airport functions may also be susceptible to damage. Structural damage may range from broken windows and wall cracks to partial building collapse. Fuel lines and tanks may be damaged, possibly resulting in fires.


Salt Lake International Airport. Photo courtesy of the Utah Office of Tourism

*Electric power and communication lines* may be above ground on poles or within below ground ducts.

Poles are usually treated wood of varying age. Electric transformers are often attached to poles. During an earthquake, these transformers may be knocked down. Voltage fluctuations have been known to cause transformers to explode or burn. Power lines swinging together may cause arcing or start fires. Ground settlement can cause below ground conduits to separate and wires to break. Telephone service will most likely be impacted by overloading of circuits, both landline and cellular.

*High-voltage electrical transmission lines. Photo courtesy of Rocky Mountain Power.*

The primary risk to electric power systems are vulnerabilities to *distribution substations*. These facilities step down power voltage for distribution to customers. They typically consist of one or more small buildings, steel towers, cables, circuit breakers and transformers. Typical damage includes breakage of porcelain bushings and insulators. Unanchored equipment, particularly large, heavy transformers may slide or overturn. This type of damage will make the substation inoperable.

*Water systems* consist of transmission trunk lines, wells, pump stations, and distribution mains. Within urban areas, the *transmission lines*, as well as the *distribution system,* consists of buried pipes. Typical pipe materials are concrete, welded or riveted steel, and ductile (flexible) iron. Failure of a pressurized large-diameter water transmission main can be catastrophic, with large quantities of water flowing through neighborhoods. The greatest risk of failure is at fault crossings, although liquefaction and shaking can cause pipe joint separation. Failure of a major aqueduct can affect downstream system pressures, which in turn impact firefighting capabilities.

Water is a basic need for life. Lack of potable water has major social and secondary economic impact. While much of our water is provided from mountain reservoirs and gravity feed, many communities supplement this by pumping *well water*. Wells may be inoperable due to several types of damage. This includes damage to the well casing caused either by ground shaking or movement. Other causes of damage may be pump failure, breakage of discharge piping or sand infiltration. Wells can be contaminated by inflow of nearby, damaged sewers. Loss of electric power will also force wells off line.

*Water pumping stations* are used to increase pressure and provide storage. They typically include a building, pump and motors, pipes, and the required electrical and control equipment. Water holding tanks are often associated with pump stations. These may be ground level tanks or tanks on elevated structures. Damage often is closely related to soil performance. Catastrophic toppling of towers may occur. Sloshing within ground level tanks often causes “elephant foot” tank wall buckling. This may be accompanied by failure of adjacent piping. Pump shafts may suffer misalignment, and heavy equipment may slide.

*Wastewater treatment plant located in Salt Lake County. Photo courtesy of South Valley Water Reclamation*

Since *sewers* are typically not pressurized, the separation of pipes may not be immediately recognized if waste water can continue to flow and the pipe is not crushed. However, failure can bring on significant environmental contamination and slow recovery efforts. The lack of pressure flow means that leaks may be harder to find. Damage to *sewer treatment plants* means raw sewerage may by-pass the facilities, causing further environmental concerns. Sewer pipes are commonly made of cast iron, cement, vitrified clay, and gasket joined polyethylene.

*Natural gas transmission lines* carry fuel at elevated pressure to distribution systems. Transmission lines are welded steel. Primary risk is associated with fault crossings and lateral ground motion. Aside from failures that might be associated with significant Wasatch fault movement, gas transmission lines can be considered very robust.

*Installation of a welded steel natural gas pipeline in Salt Lake County. Photo courtesy of Quester Gas Company.*

*Natural gas distribution lines* are similarly constructed of welded steel, with continuously fused polyethylene pipe also used. The natural gas system essentially extends to every road and street in the Salt Lake Valley that has buildings along it. The system is tied together as one large grid with few dead-end legs. This system is segmented with valves which can isolate geographic grids if a catastrophic situation warrants it. Distribution systems leaks will primarily (though not exclusively) be associated with fault rupture.

It is very unlikely that the number of failures will cause the network to de-pressurize to the extent that the system is lost. However, the loss of firefighting capacity due to water system breaks could force the shutdown of segments of the gas system as a precautionary measure. The primary cause of natural gas leakage will likely be residential water heater failure. This will be caused by ground shaking or building collapse. Based on the experience of California gas companies, it is reasonable to assume that natural gas service will be restored to the majority of customers (assuming the structure is safe to occupy) within two weeks.[36]

Several major *oil refineries* are adjacent to the Wasatch fault, in south Davis County. The greatest risk of failure is typically to cylindrical tankage, which can rupture and spill their contents. Given the complexity of a refinery, another major concern after a severe earthquake is fire, which could spread through the facility. Damage to piping, equipment and critical structures may also make the facility inoperative for an extended period of time.

With the possible exception of above ground power and communication lines, and specially engineered ductile pipelines, we can assume that all lifelines will be severed at fault crossings. Liquefaction will cause extensive joint separation on rigid pipes and conduits.

We cannot overemphasize the risk of co-location or co-dependence issues among lifelines. Failure of a water main may undermine soil so other adjacent utilities fail. Fire caused by failure of a gas main may damage adjacent power and communication lines. Loss of electric power will cause emergency office activities for all utility providers to use back-up power generation. This in turn will put pressure on the use of limited-stored fuel supplies that back-up power generation depends upon. Lack of electric power will mean gas fired furnaces will not operate due to electronic thermostat controls and fan motors. Roadway damage will make responding to other lifeline emergencies more difficult.

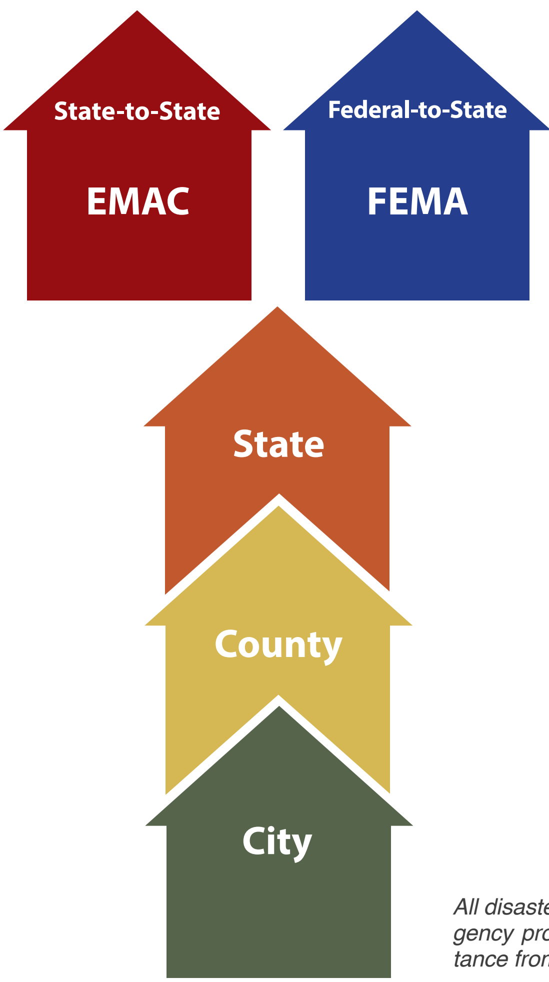
# Response

The scenario magnitude 7 earthquake will likely occur without warning in Utah's most populous region. Planning for post-earthquake response is imperative, as people directly affected by the event may ignore, be unaware of, not understand, or be incapable of receiving announcements or warnings. Law enforcement will be insufficient to maintain order in some of the affected area. Local jurisdictions have limited resources, which will affect their ability to respond, as an estimated 30 percent of first responders, government officials, emergency management, and other support agency personnel in the area will be unable or unavailable to perform their duties.

When a city has exhausted all of it resources, they request assistance from the county Emergency Operations Center (EOC). When the county has exhausted all of its resources, they request assistance from the state EOC. When the state has exhausted all of its resources, they can request assistance through the Emergency Management Assistance Compact. This compact is a state-to-state compact providing quick access to select, needed resources. The state can also request help from the federal government through FEMA (see diagram below left).

This scenario presents a representative operational picture of the disaster. Using this operational picture, jurisdictions can prepare response plans prior to the earthquake. The response planning process can identify resource gaps at all levels of government. Knowing these gaps, all jurisdictions can identify where they may anticipate receiving the needed resources. An example of a plan that is using this scenario is the Wasatch Range Catastrophic Earthquake Response Plan,[37] a joint plan between the State of Utah and FEMA.

Once developed, response plans can be tested using tabletop to full-scale exercises. Using the outputs from the Hazus analysis, exercise developers create realistic situations based on quality data. Examples of these types of exercises are the 2012 and 2013 Great Utah ShakeOut Exercises and the 2014 Vigilant Guard Exercise (see photos on next page).[38]




*All disasters start at the local level. Through the declaration of emergency process, lower level jurisdictions can request disaster assistance from the next higher level of government.*

## Additional Response and Recovery Resources:

- **National Disaster Recovery Framework** designed to meet the needs of states and communities in their recoveries
- **Public Assistance Grant Program** provides assistance to State, Tribal and local governments
- **Individual and Household Program** provides assistance for individuals with limited resources
- **Community Emergency Response Teams** provide neighborhood teams for local response
- **Disaster Recovery Center** provides recovery services for individuals


ESF 8
ESF 10
ESF 4


MURRAY
The Great
Utah
Be
Ready
Utah
ShakeOut


DROP!
COVER!
HOLD ON!


American
Red Cross
American
Red Cross
Disaster Relief
VIGILANT GUARD | UTAH 2014
A MULTIAGENCY EARTHQUAKE
RESPONSE EXERCISE
NOVEMBER 3 - 6, 2014
#VGUT14
VIGILANT
GUARD

Scenarios also can be used to position assets and capabilities before an event, and to identify locations that may be affected less from ground-shaking and other earthquake effects. An example of this is the location of the state's alternate EOC at a geologically preferable setting in Utah County. Maps can be made now that identify possible staging areas (Figure 26). These maps could also include potential resources like location of police and fire personnel or hospitals.

Scenarios also provide the scope of damage and estimate potential resource needs. This information can be used in advance to develop plans for response at all levels of government.

The rest of this section details the scope of damage for this magnitude 7.0 scenario.

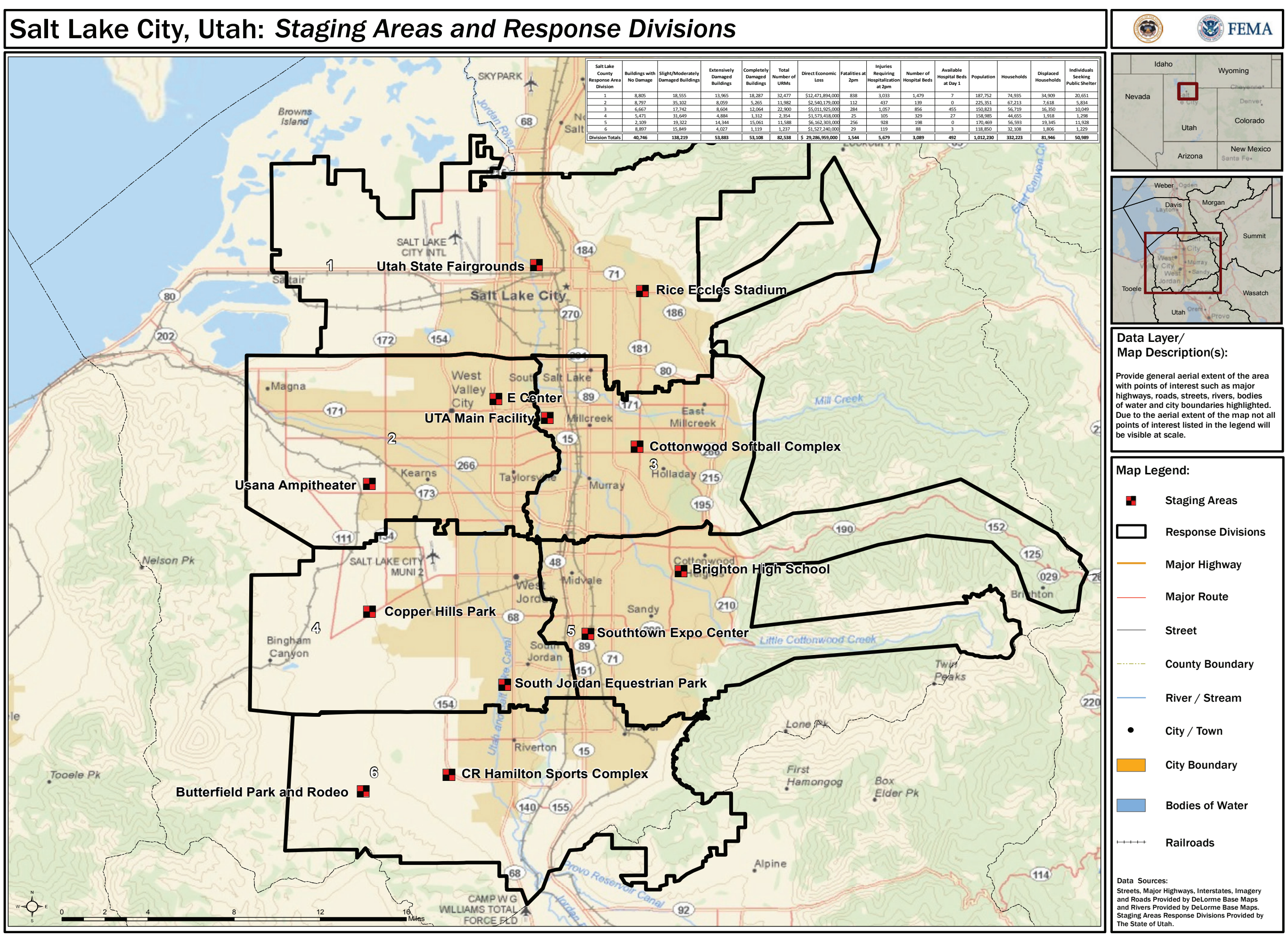
## Inspection Needs (Figure 27)

Hazus modeling estimates about 308,100 buildings will have damage ranging from slight to complete; 275,000, or 89 percent, of these are single-family or other residential buildings.


*Notice to resident of red tagged house - 2011 $M_W$ 6.1 Christchurch, New Zealand earthquake. Photo: EERI/David Swanson.*

Communities will need to perform safety inspections on these buildings in a timely manner to get families back in their homes and business owners back into their buildings.

The Hazus data show that 2,380 building inspectors will be needed to complete the necessary safety inspections within 30 days after the earthquake.




| Salt Lake County Response Area Division | Buildings with No Damage | Slight/Moderately Damaged Buildings | Extensively Damaged Buildings | Completely Damaged Buildings | Total Number of URMs | Direct Economic Loss | Fatalities at 2pm | Injuries Requiring Hospitalization at 2pm | Number of Hospital Beds | Available Hospital Beds at Day 1 | Population | Households | Displaced Households | Individuals Seeking Public Shelter |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 8,805 | 18,555 | 13,965 | 18,287 | 32,477 | $12,471,894,000 | 838 | 3,033 | 1,479 | 7 | 187,752 | 74,935 | 34,909 | 20,651 |
| 2 | 8,797 | 35,102 | 8,059 | 5,265 | 11,982 | $2,540,179,000 | 112 | 437 | 139 | 0 | 225,351 | 67,213 | 7,618 | 5,834 |
| 3 | 6,667 | 17,742 | 8,604 | 12,064 | 22,900 | $5,011,925,000 | 284 | 1,057 | 856 | 455 | 150,823 | 56,719 | 16,350 | 10,049 |
| 4 | 5,471 | 31,649 | 4,884 | 1,312 | 2,354 | $1,573,418,000 | 25 | 105 | 329 | 27 | 158,985 | 44,655 | 1,918 | 1,298 |
| 5 | 2,109 | 19,322 | 14,344 | 15,061 | 11,588 | $6,162,303,000 | 256 | 928 | 198 | 0 | 170,469 | 56,593 | 19,345 | 11,928 |
| 6 | 8,897 | 15,849 | 4,027 | 1,119 | 1,237 | $1,527,240,000 | 29 | 119 | 88 | 3 | 118,850 | 32,108 | 1,806 | 1,229 |
| **Division Totals** | **40,746** | **138,219** | **53,883** | **53,108** | **82,538** | **$ 29,286,959,000** | **1,544** | **5,679** | **3,089** | **492** | **1,012,230** | **332,223** | **81,946** | **50,989** |

*Figure 26. Map of possible emergency staging areas and response divisions in the Salt Lake City area.*

*Red Cross volunteers in Houston, Texas, discuss a floor plan to make the best use of the space in the abandoned mall that would ultimately house almost a thousand Houston residents following Hurricane Ike. FEMA contributions keep shelters such as this one operating. Photo: Greg Henshall/FEMA.*

## Displaced Households (Figure 28)

Hazus estimates that nearly 84,400 households will be displaced after the earthquake. The U.S. Census estimates the average household size in Utah at 3.12 persons, so the scenario indicates that over 263,300 individuals will be displaced after the earthquake. Of this number, federal and state planners estimate the number of individuals seeking shelter immediately after the earthquake to be about 53,000.


*These non-ductile columns failed in shear and then collapsed under the weight of the bridge - 1994 $M_W$ 6.7 Northridge, California earthquake. Photo: EERI.*

## Damage to Roads and Bridges (Figure 29)

The ability to move about after the earthquake is imperative. Hazus can estimate the likelihood of damage to bridges and road segments, so planners can estimate the number of bridge inspectors that will be needed for inspections. The scenario shows that more than 1,800 bridges are found in the scenario region. Hazus estimates that nearly 560 of those bridges will need priority inspections relative to their importance in the transportation system. Planners estimate the need for over 70 bridge inspectors.

## Hospital Bed Availability (Figure 30)

Hospital bed availability is most critical after the earthquake. Hazus estimates that there will be nearly 9,300 injuries requiring hospitalization, but only about 3,200 available beds. Hazus estimates that all hospitals in Salt Lake County and the two hospitals in southern Davis County all have a high probability of experiencing at least moderate damage.

*HVAC service outage at the Holy Cross Medical Center in Sylmar caused evacuation of all patients. The damage shown occurred when suspended fans in the penthouse swung and impacted louver panels. This building, a steel frame, also suffered many weld fractures that were not discovered until well after the facility had been restored to service - 1994 $M_W$ 6.7 Northridge, California earthquake. Photo: EERI.*

## Search and Rescue Needs (Figure 31)

Using Hazus estimates of building damage, planners can calculate the number of possible building collapses. These estimates, in turn, can be the basis for emergency managers requesting search and rescue teams from FEMA. Hazus estimates more than 7,800 out of 55,400 red-tagged buildings would collapse in this earthquake scenario. Most of these collapsed buildings will be residential structures.

## Vulnerable Populations (Figure 32)

Using Hazus, planners can see the distribution of different vulnerable populations that are in the disaster area along with the applicable information.

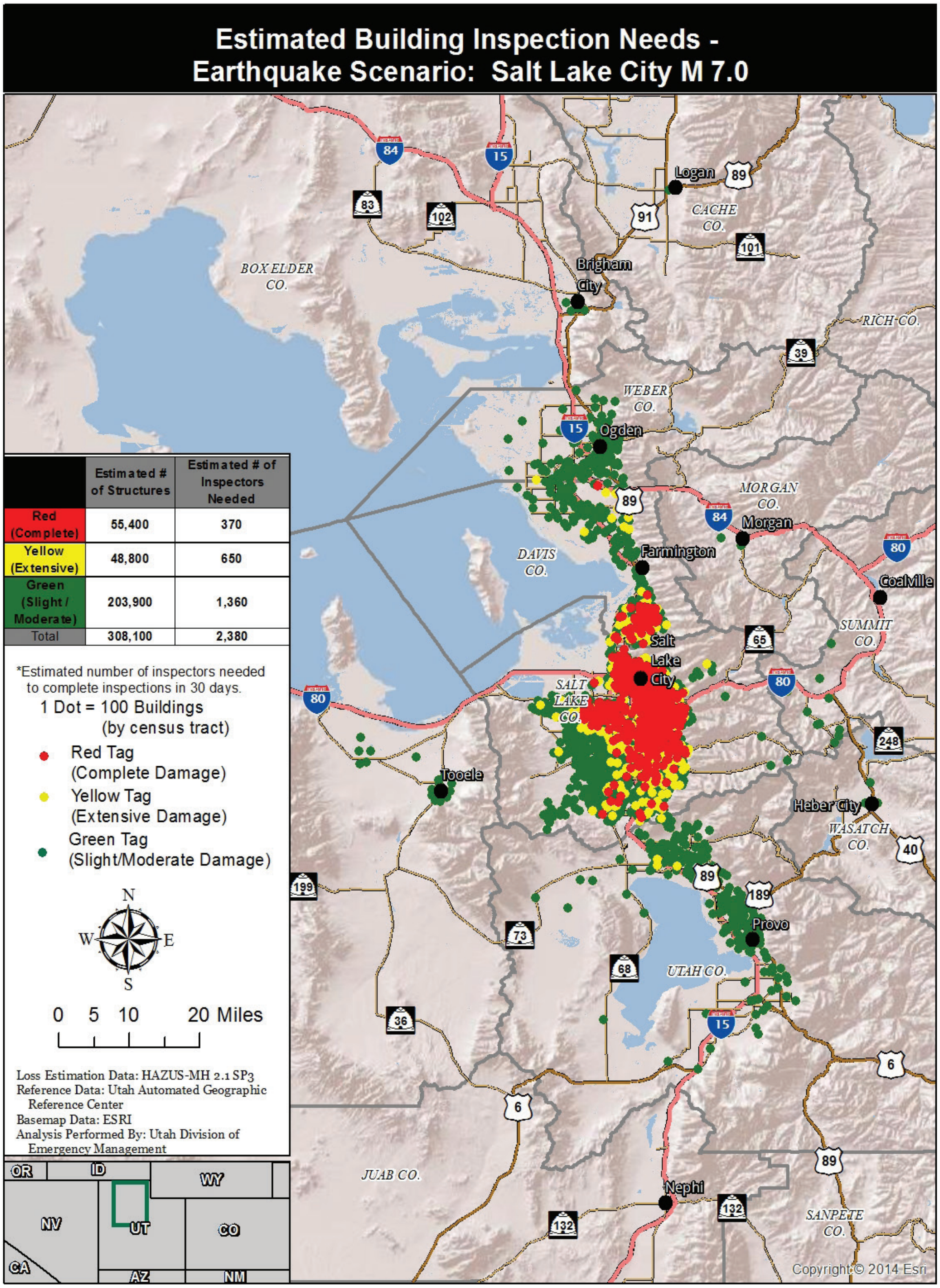



*Figure 27. This map highlights where Hazus estimates the building damage will occur. Each dot represents 100 buildings per census tract. When the damaged building count falls below this level, there will be no indication of any damage on the map. However, there may be many areas that need safety inspections that do not appear on the map.*

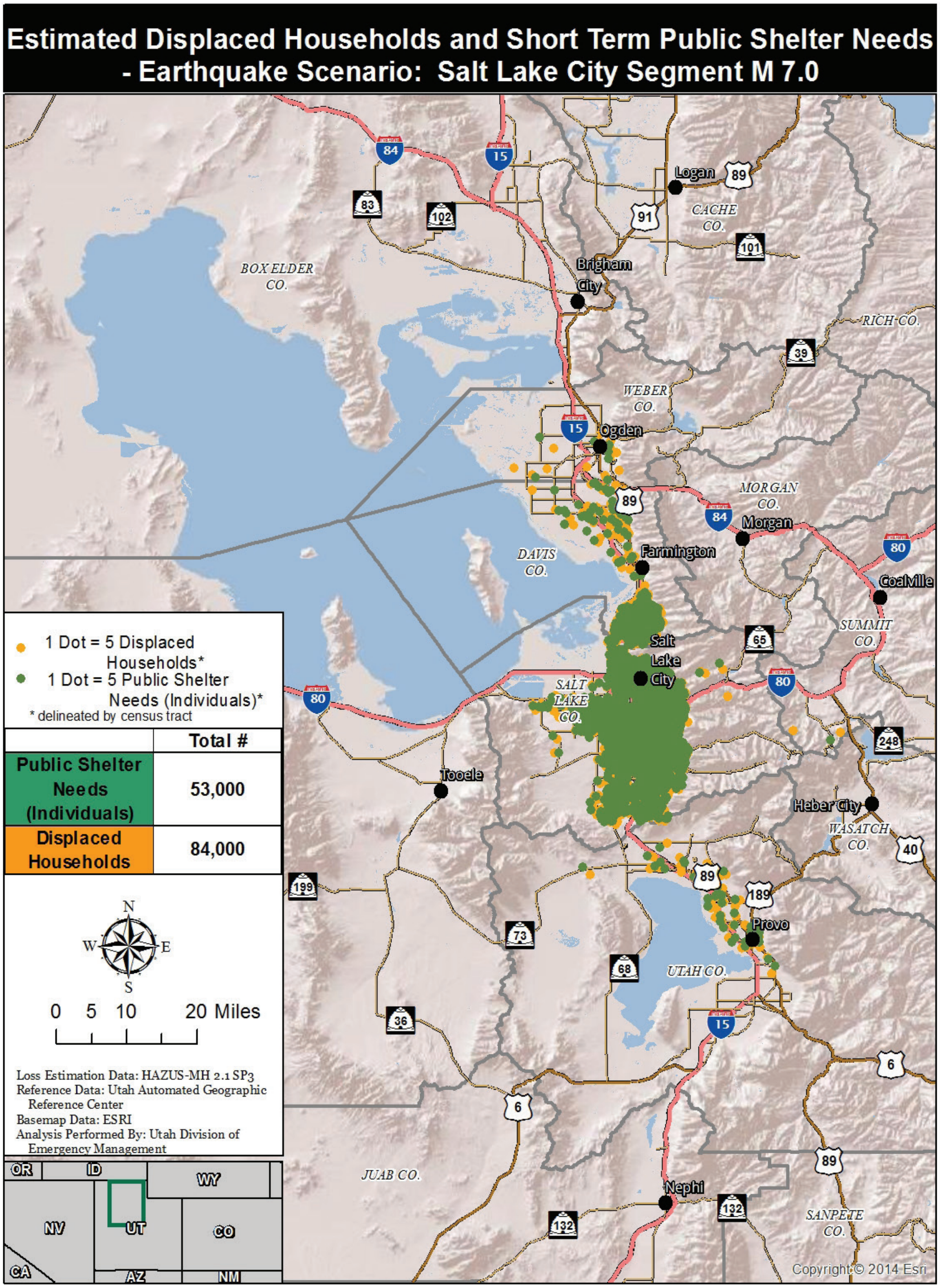



*Figure 28. This map highlights where Hazus estimates displaced households and individuals seeking shelters will occur. The orange dots represent the number of displaced households and the green dots represent individuals seeking shelter (five each, respectively) per census tract. But if the count falls below this level, the map will indicate no displacement or shelter needs, even though there may be many areas of displaced households or individuals seeking shelters.*

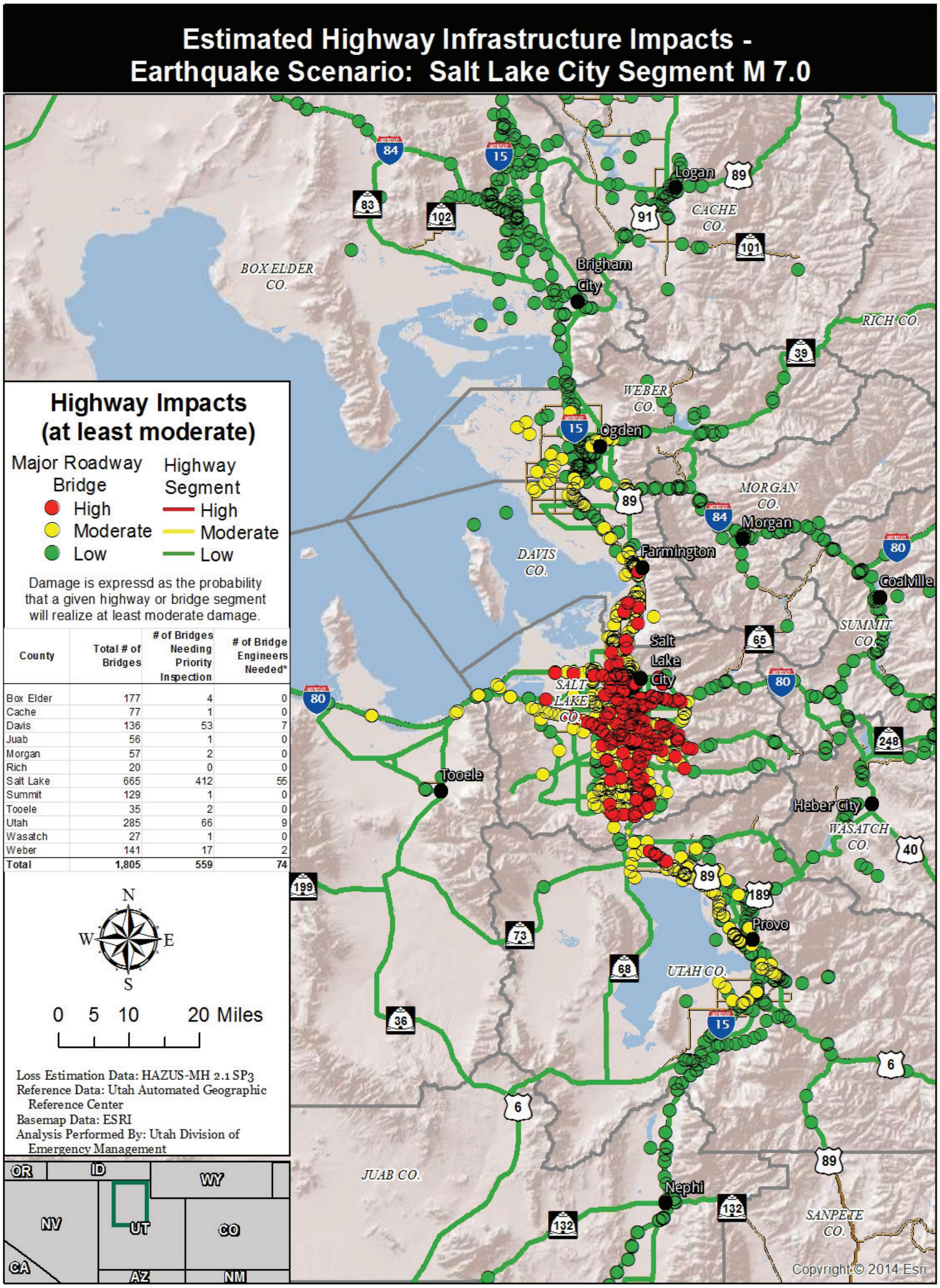
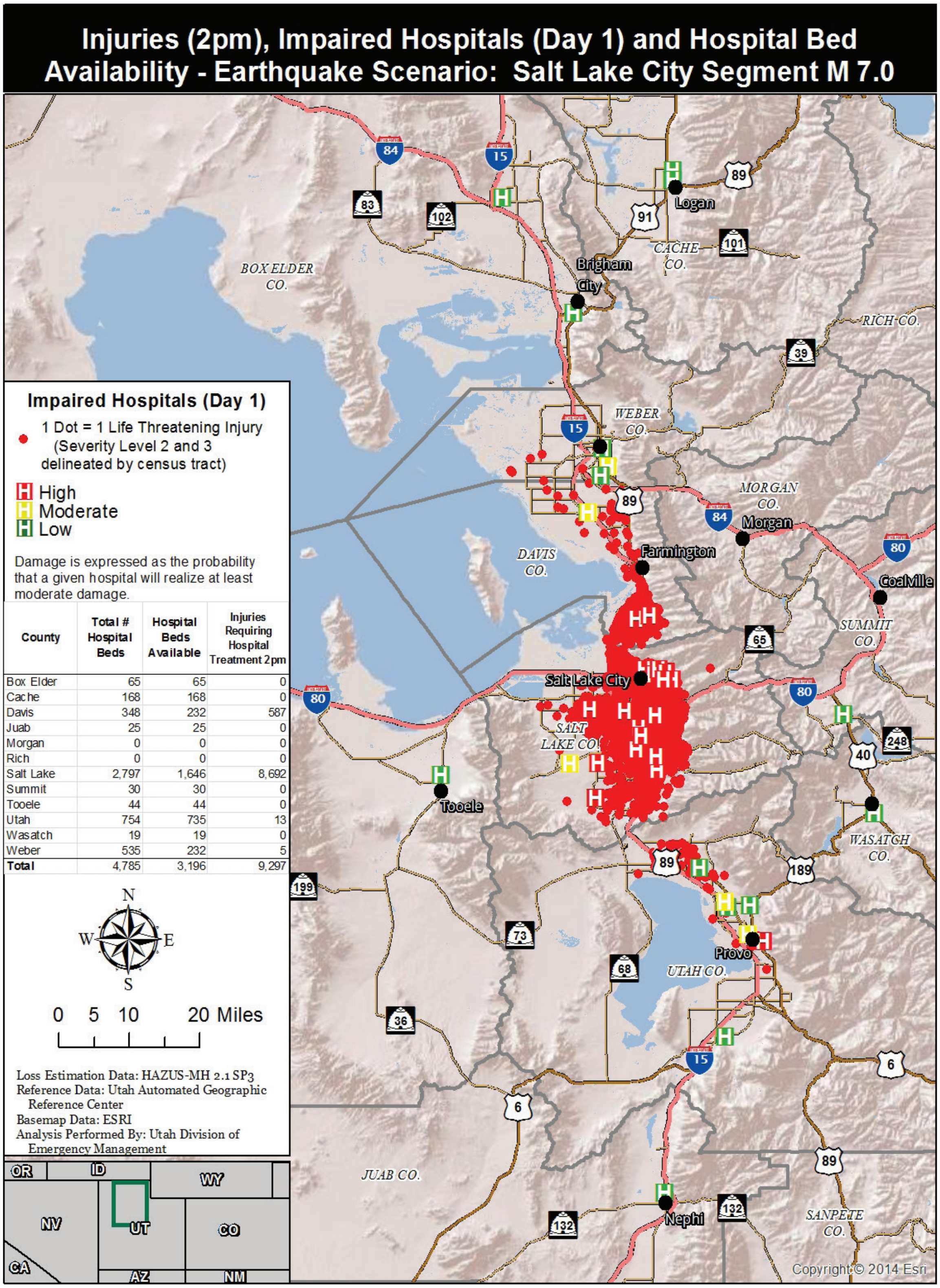
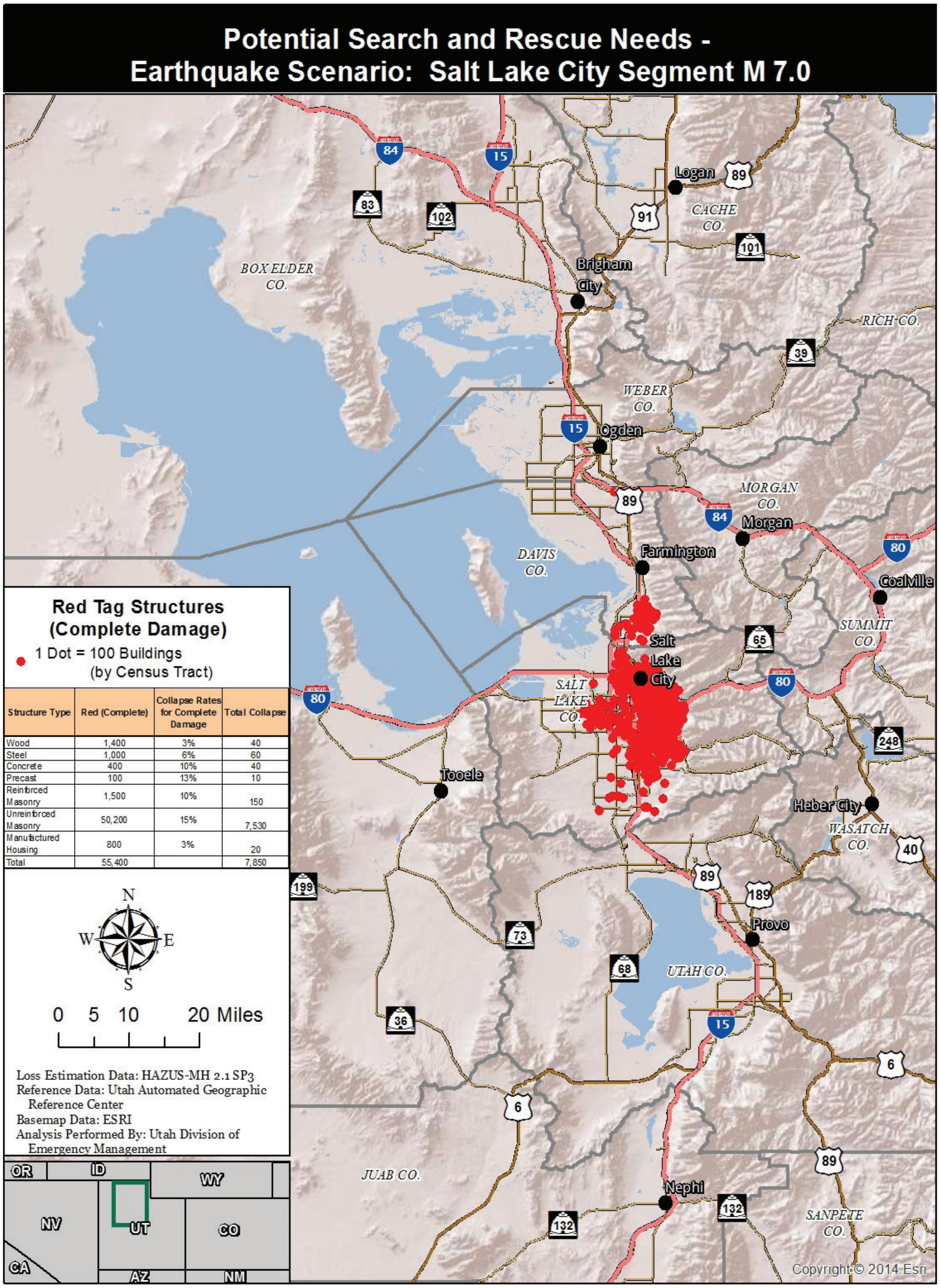



*Figure 29. This map highlights where Hazus estimates the probability that at least moderate damage will occur to major roadway bridges or highway segments.*



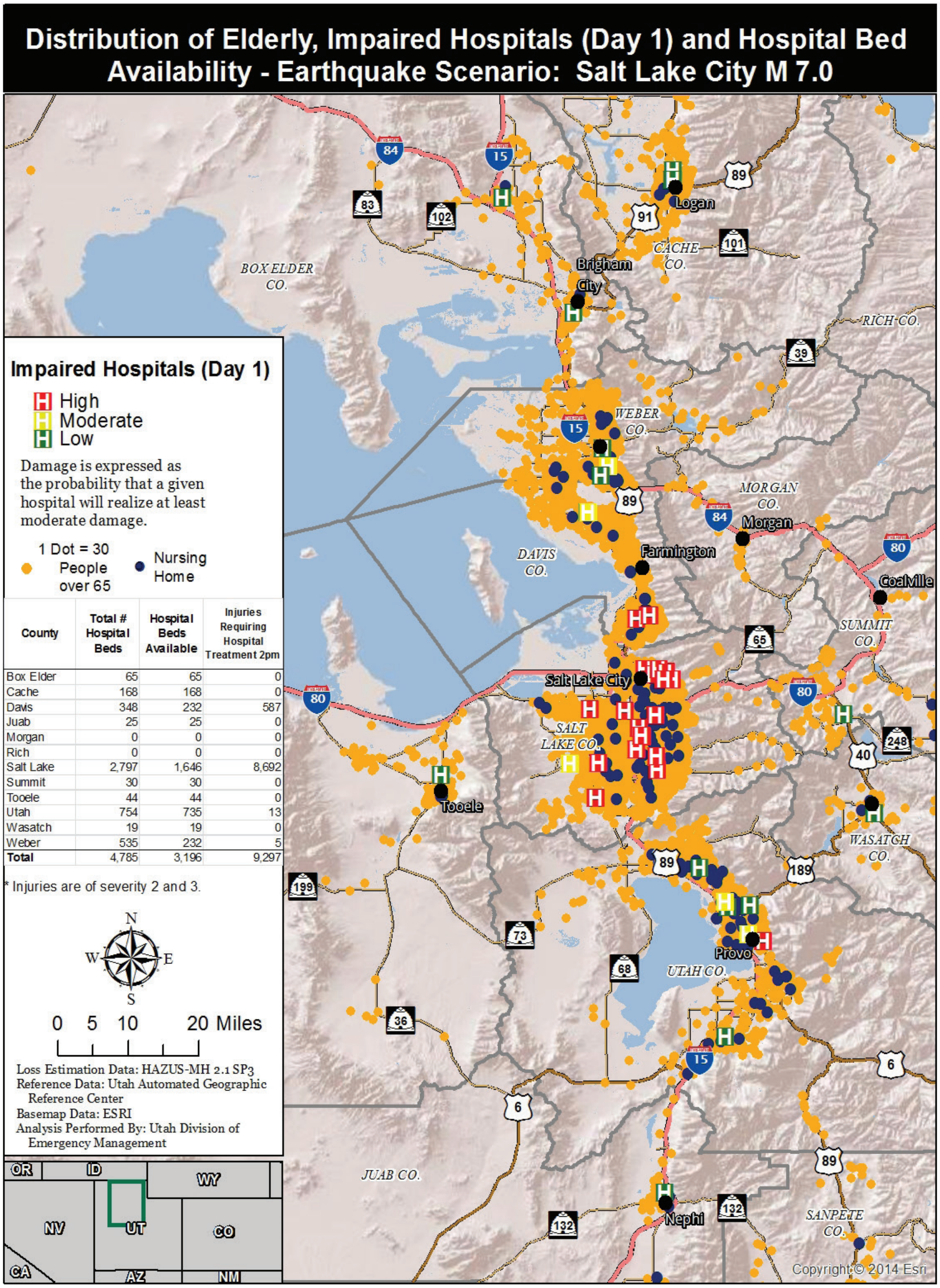

| County | Total # Hospital Beds | Hospital Beds Available | Injuries Requiring Hospital Treatment 2pm |
|---|---|---|---|
| Box Elder | 65 | 65 | 0 |
| Cache | 168 | 168 | 0 |
| Davis | 348 | 232 | 587 |
| Juab | 25 | 25 | 0 |
| Morgan | 0 | 0 | 0 |
| Rich | 0 | 0 | 0 |
| Salt Lake | 2,797 | 1,646 | 8,692 |
| Summit | 30 | 30 | 0 |
| Tooele | 44 | 44 | 0 |
| Utah | 754 | 735 | 13 |
| Wasatch | 19 | 19 | 0 |
| Weber | 535 | 232 | 5 |
| **Total** | 4,785 | 3,196 | 9,297 |

*Figure 30. This map illustrates the relationship of injuries to damaged hospitals. Planners using the highway bridge and road segment map and the impaired hospital and injury map can develop strategies on how best to move patients to area hospitals or out-of-area hospitals.*




| Structure Type | Red (Complete) | Collapse Rates for Complete Damage | Total Collapse |
|---|---|---|---|
| Wood | 1,400 | 3% | 40 |
| Steel | 1,000 | 6% | 60 |
| Concrete | 400 | 10% | 40 |
| Precast | 100 | 13% | 10 |
| Reinforced Masonry | 1,500 | 10% | 150 |
| Unreinforced Masonry | 50,200 | 15% | 7,530 |
| Manufactured Housing | 800 | 3% | 20 |
| Total | 55,400 | | 7,850 |

*Figure 31. This map illustrates the location of potential building collapse. Each dot on the map represents 100 buildings per census tract. When the damaged building count falls below this level, there will be no indication of any damage on the map, though there may in fact be many more damaged buildings.*




| County | Total # Hospital Beds | Hospital Beds Available | Injuries Requiring Hospital Treatment 2pm |
|---|---|---|---|
| Box Elder | 65 | 65 | 0 |
| Cache | 168 | 168 | 0 |
| Davis | 348 | 232 | 587 |
| Juab | 25 | 25 | 0 |
| Morgan | 0 | 0 | 0 |
| Rich | 0 | 0 | 0 |
| Salt Lake | 2,797 | 1,646 | 8,692 |
| Summit | 30 | 30 | 0 |
| Tooele | 44 | 44 | 0 |
| Utah | 754 | 735 | 13 |
| Wasatch | 19 | 19 | 0 |
| Weber | 535 | 232 | 5 |
| **Total** | 4,785 | 3,196 | 9,297 |

*Figure 32. This map shows the population over 65 years of age as well as nursing-home locations. These two databases will aid in recognizing limited-mobility populations. Additionally, the map shows the locations of hospitals that may be needed to aid these vulnerable populations. Each dot represents 30 individuals per census tract. When the individual count falls below this level, there will be no indication of individuals over 65 on the map, though there may be many more.*

# Recovery

The recovery phase from a disaster begins shortly after the response phase starts. Imagine two wedges: a full wedge of Response and a thin wedge of Recovery at the beginning of the disaster. Over the course of the first two weeks, the Response wedge thins as the Recovery wedge thickens.

In the same way that the scenario provides the scope of damage needed to plan for response, it also provides information needed to plan for recovery.

## Direct Building Economic Loss (Figure 33)

Hazus provides an estimate for the number of buildings damaged in categories ranging from none to complete. From these estimates, planners can calculate the number of building inspectors that will be needed to complete the safety assessment within 30 days. This assessment then can be the basis for a request for a Preliminary Damage Assessment (PDA) to be conducted by FEMA, the State of Utah, and local jurisdictions.

The PDA process will be looking at damages that can be applied to two types of assistance programs: the Individual and Households Program (IHP) for homeowners and the Public Assistance (PA) Grant Program for debris removal, emergency protective measures, and the repair, replacement, or restoration of eligible public facilities and infrastructure.

## Utilities (Figure 34)

Most people are so accustomed to utilities working that they barely consider how they would adapt to not having them. Hazus has provided probabilities of damage to these utilities. This type of information aids planners who have the responsibility to estimating when services can be restored. Variables they will consider are extent of damage, availability of replacement materials, availability of equipment, and a workforce to complete the repairs.

## Debris (Figure 35)

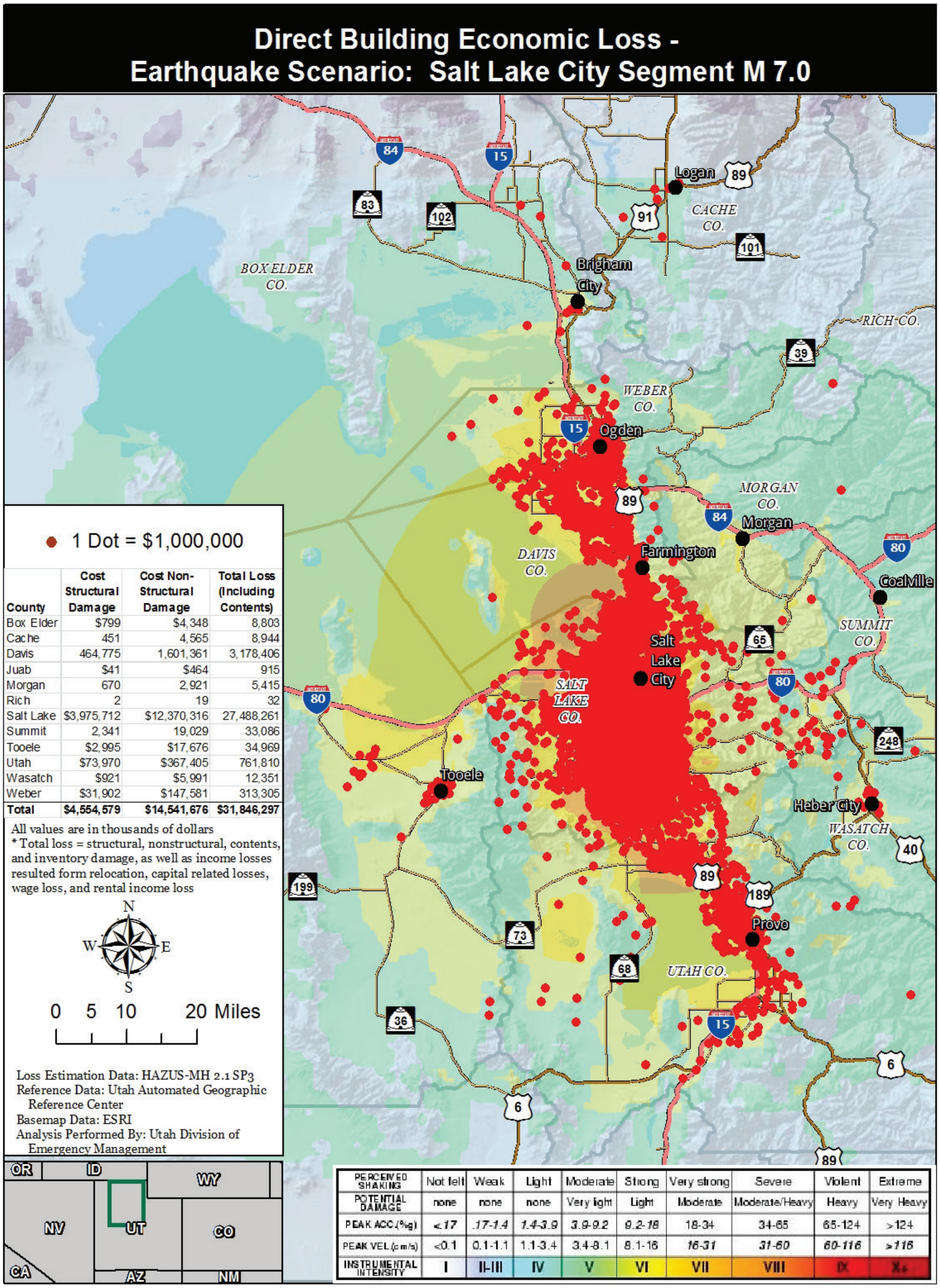
Based on building losses, Hazus can estimate the amount of debris that could be generated from the scenario earthquake. Having these estimates, planners can develop debris management plans before the disaster happens. This could be critical to communities that will be requesting reimbursement from FEMA for debris removal. Prior to February 2011, FEMA spent more than $8 billion over the past 11 years for post-disaster debris removal.


*Debris from the catastrophic collapse of the Pyne Gould Corporation - 2011 $M_W$ 6.1 Christchurch, New Zealand earthquake. Photo: EERI/Troy Morgan.*

## Non-English Speaking Communities (Figure 36)

When trying to recover from any kind of a disaster, one of the problems that emergency managers have to deal with is providing the public with disaster-related information. For most large metropolitan areas, multiple languages are spoken as the primary language. Using U.S. Census data, the scenario can show where planners, first responders, aid workers, and emergency managers can anticipate having a population that cannot speak English.


*Detail of unsafe posted single family dwelling unit - 1994 $M_W$ 6.7 Northridge, California earthquake. Photo: EERI*




| County | Cost Structural Damage | Cost Non-Structural Damage | Total Loss (Including Contents) |
|---|---|---|---|
| Box Elder | $799 | $4,348 | 8,803 |
| Cache | 451 | 4,565 | 8,944 |
| Davis | 464,775 | 1,601,361 | 3,178,406 |
| Juab | $41 | $464 | 915 |
| Morgan | 670 | 2,921 | 5,415 |
| Rich | 2 | 19 | 32 |
| Salt Lake | $3,975,712 | $12,370,316 | 27,488,261 |
| Summit | 2,341 | 19,029 | 33,086 |
| Tooele | $2,995 | $17,676 | 34,969 |
| Utah | $73,970 | $367,405 | 761,810 |
| Wasatch | $921 | $5,991 | 12,351 |
| Weber | $31,902 | $147,581 | 313,305 |
| **Total** | **$4,554,579** | **$14,541,676** | **$31,846,297** |

| PERCEIVED SHAKING | Not felt | Weak | Light | Moderate | Strong | Very strong | Severe | Violent | Extreme |
|---|---|---|---|---|---|---|---|---|---|
| POTENTIAL DAMAGE | none | none | none | Very light | Light | Moderate | Moderate/Heavy | Heavy | Very Heavy |
| PEAK ACC.(%g) | <.17 | .17-1.4 | 1.4-3.9 | 3.9-9.2 | 9.2-18 | 18-34 | 34-65 | 65-124 | >124 |
| PEAK VEL.(cm/s) | <0.1 | 0.1-1.1 | 1.1-3.4 | 3.4-8.1 | 8.1-16 | 16-31 | 31-60 | 60-116 | >116 |
| INSTRUMENTAL INTENSITY | I | II-III | IV | V | VI | VII | VIII | IX | X+ |

*Figure 33. This map provides monetary estimates of losses for building damage across all categories of buildings. Each dot represents an estimated $1 million in building damage per census tract. When the dollar value falls below this level, there will be no indication of any dollar losses on the map. However, there may be many more areas that have losses that do not appear on the map. For these areas, refer to the table on the map.*

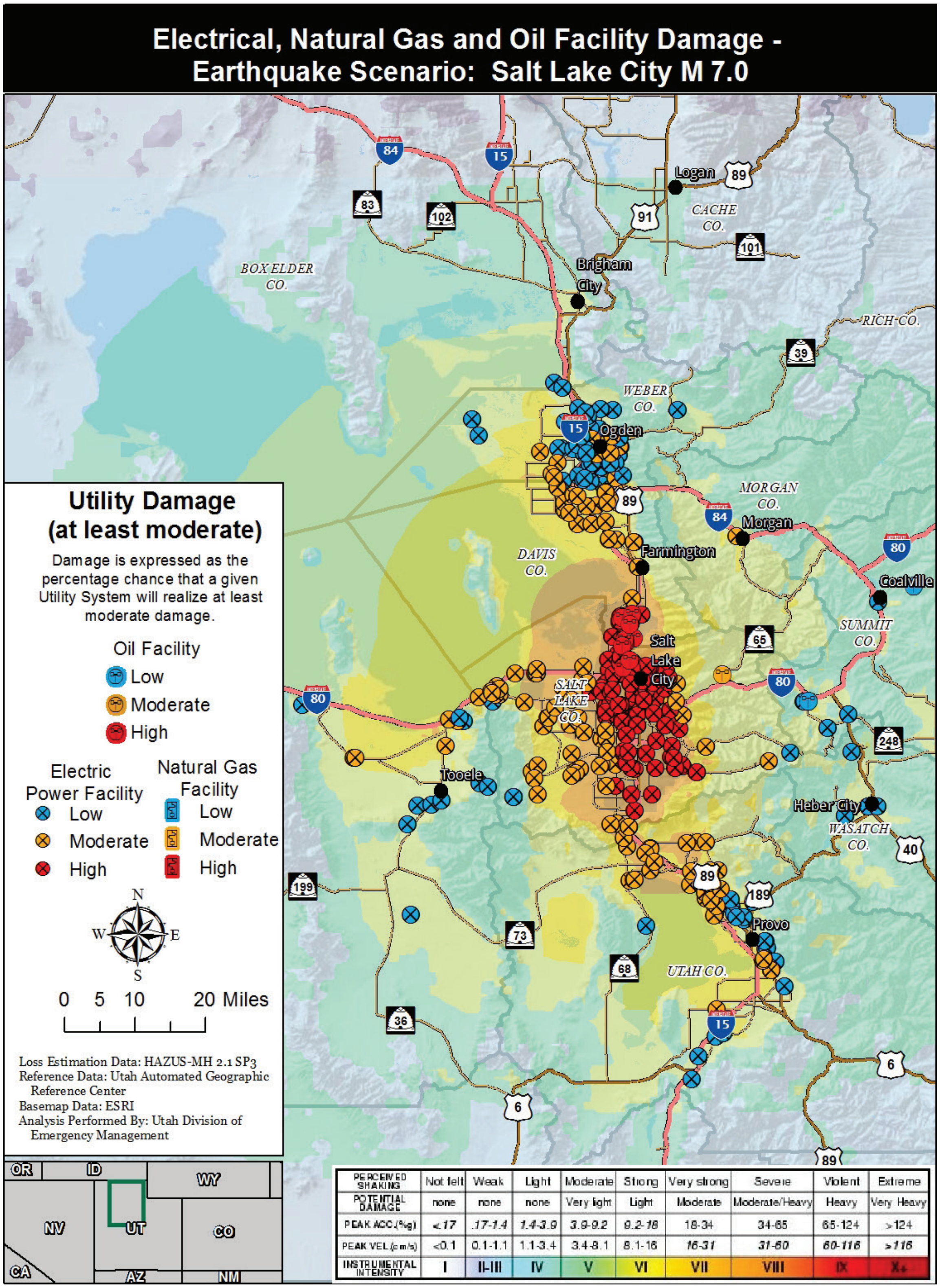
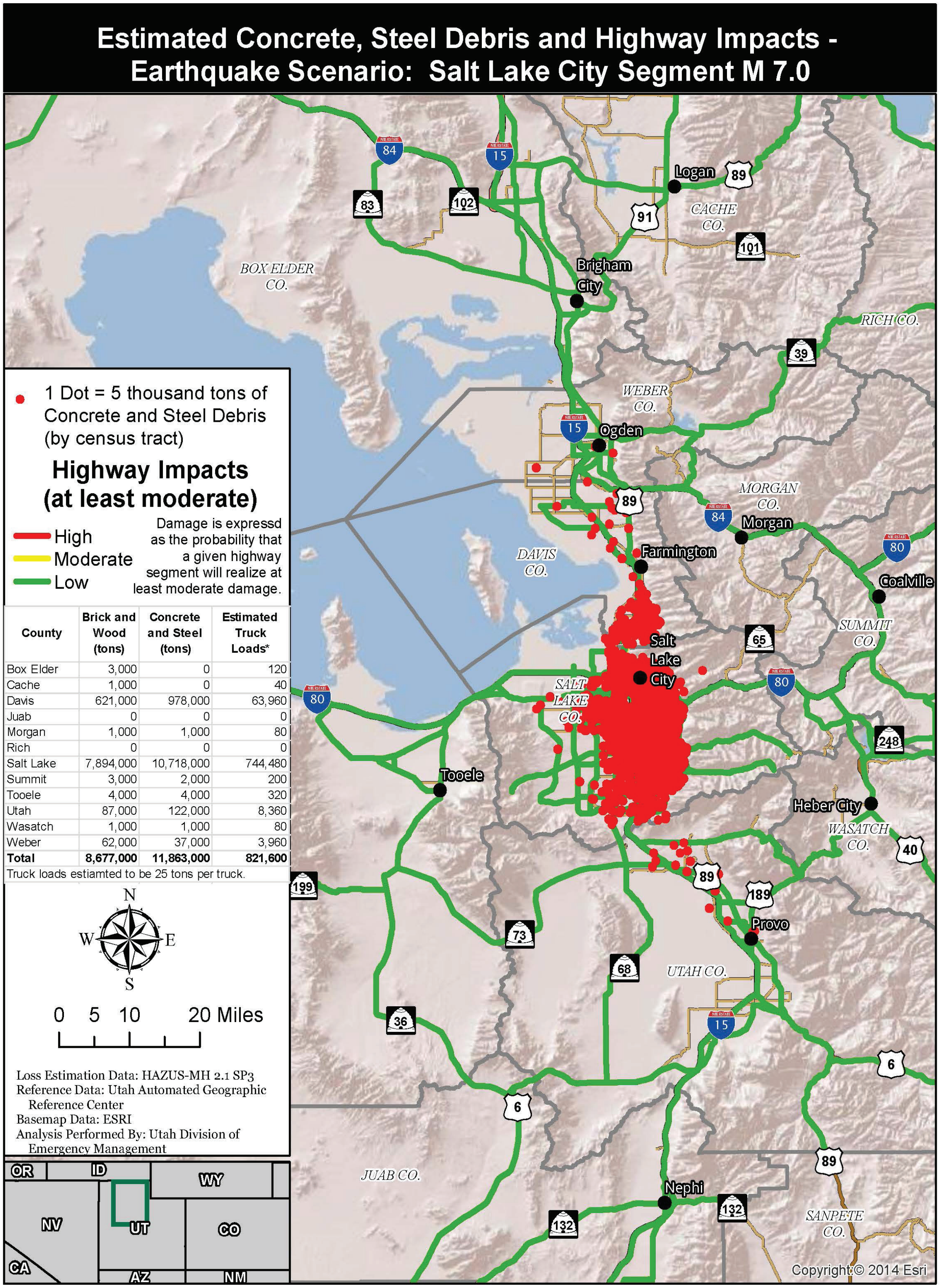



*Figure 34. This map represents the probability of at least moderate damage to the electric, natural gas, and oil facilities. The map does not show damage to the different distribution systems.*




| County | Brick and Wood (tons) | Concrete and Steel (tons) | Estimated Truck Loads* |
|---|---|---|---|
| Box Elder | 3,000 | 0 | 120 |
| Cache | 1,000 | 0 | 40 |
| Davis | 621,000 | 978,000 | 63,960 |
| Juab | 0 | 0 | 0 |
| Morgan | 1,000 | 1,000 | 80 |
| Rich | 0 | 0 | 0 |
| Salt Lake | 7,894,000 | 10,718,000 | 744,480 |
| Summit | 3,000 | 2,000 | 200 |
| Tooele | 4,000 | 4,000 | 320 |
| Utah | 87,000 | 122,000 | 8,360 |
| Wasatch | 1,000 | 1,000 | 80 |
| Weber | 62,000 | 37,000 | 3,960 |
| **Total** | **8,677,000** | **11,863,000** | **821,600** |

Truck loads estiamted to be 25 tons per truck.

*Figure 35. This map provides Hazus estimates for the amount of debris that may be generated from this scenario earthquake. Each dot represents 5,000 tons of concrete and steel debris per census tract. When the tonnage value falls below this level, there will be no indication of debris tonnage on the map. However, there may be many areas that have debris tonnage that does not appear on the map.*

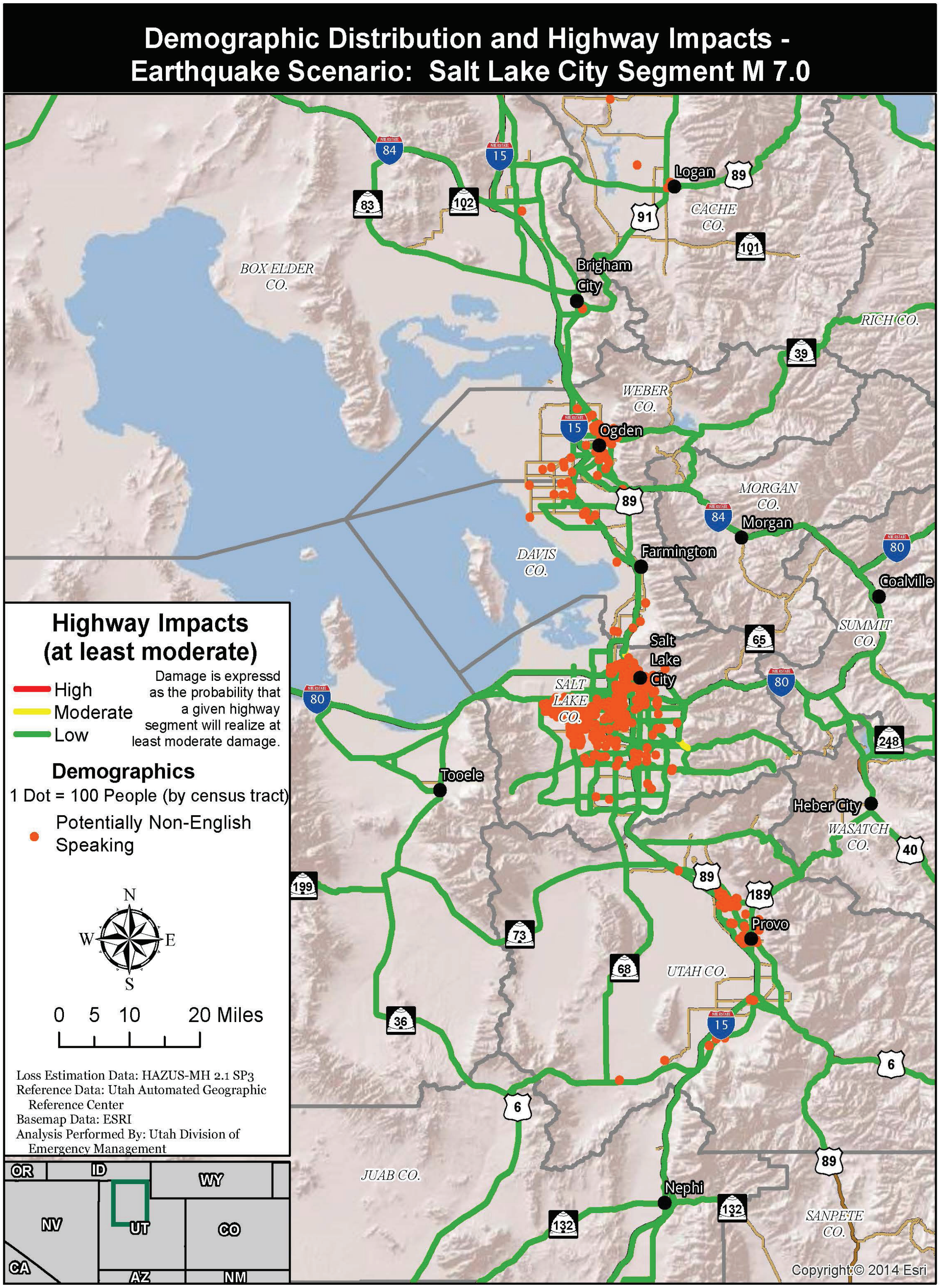
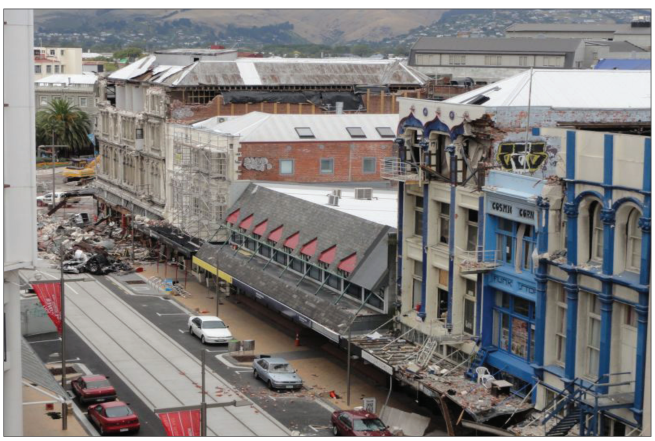



*Figure 36. This map shows where the potentially non-English speaking populations can be found. Each dot represents 100 non-English speaking individuals per census tract. When the number of individuals falls below this level, there will be no indication of these individuals on the map. However, there may be many more areas that have non-English speaking individuals.*

# Conclusion

## Working to Make Utah More Disaster Resilient

This scenario report describes the impact expected from a magnitude ($M_W$) 7.0 earthquake on the Salt Lake City segment of the Wasatch fault in terms of casualties, damage, losses, and disruption. The picture is a daunting one. To get a graphic preview of what the Wasatch Front may experience after a magnitude 7 earthquake, one only has to look at the example of the $M_W$ 6.1 earthquake that devastated Christchurch, New Zealand, in February 2011.[39] A large portion of Christchurch's central business district, filled with earthquake-vulnerable unreinforced masonry buildings, was red-tagged as off-limits. Many buildings were demolished and many remained unusable while the city recovered. Portable toilets were not distributed until day 6, and there was a shortage of them. More than a year after the disaster, many households still lacked functional wastewater plumbing.



*Damage to Central Business District. Mostly collapse of URM - 2011 $M_W$ 6.1 Christchurch, New Zealand earthquake. Photo: EERI/Mary Comerio.*

The scenario earthquake in the Salt Lake Valley similarly will pose challenges as officials quickly try to assess damages and determine how to restore buildings for safe occupancy. The damages to infrastructure will also demand rapid evaluation, putting building officials, politicians, and utility companies at the forefront of policymaking. Volatile public reactions and decision-making pressures after the earthquake will be part of the mix. Pressures to recover quickly will need to be balanced with future public safety. Some decisions may prove to be harmful in the long run, but necessary in the short term. Full recovery will take years.

*Collapse of URM church - 2011 $M_W$ 6.1 Christchurch, New Zealand earthquake. Photo: EERI/Justin Marshall.*

Utah must prepare to withstand a magnitude 7 urban earthquake in the Salt Lake Valley, prepare to respond in the immediate 72-hour aftermath, and prepare for the hard work of recovering in the following days and months. How will more than 200,000 displaced residents be able to resume their normal lives? How will cities deliver potable water and rebuild destroyed sewer and water treatment facilities? How will rescue workers reach population centers when freeways, highways, and surface streets are impassable? How will the estimated economic losses of more than $33 billion be dealt with? How will the state cope with added long-term losses to its economic and social health? What will be done to keep large employers who have operations elsewhere from leaving? How are residents going to be able to take care of themselves if their businesses, or the companies they work for, are no longer viable? Our scenario does not seek to answer such questions but raises them to motivate pre-disaster planning at all levels of government.

While Utah residents have a history of rootedness in their communities and a deserved reputation for in-


*Collapse of URM building - 2011 $M_W$ 6.1 Christchurch, New Zealand earthquake. Photo: EERI/Justin Marshall.*

dustry and collective concern, there are obstacles to recovery embedded in this history. Perhaps the most significant challenge relates to building materials. As Utah was settled and grew, residents were not as able to rely on lumber to build as were settlers on the East Coast or in the Pacific Northwest, resulting in a heavy reliance on brick and stone construction.

*URM retrofitted building - 2011 $M_W$ 6.1 Christchurch, New Zealand earthquake. Photo: EERI/Fred Turner.*

Most of the masonry buildings built in Utah before the 1970s are unreinforced and therefore vulnerable to heavy damage and collapse during a magnitude 7.0 earthquake and its following aftershocks. Hazus loss estimates for our scenario are based on an estimate that 60 percent of the building stock consists of unreinforced masonry (URM) buildings. These buildings can be retrofitted to make them more resilient. Building codes already are adapting to seismic safety needs, but perhaps it is time for Utah decision-makers to harden their resolve to protect the public with even tougher laws.

While earthquake disasters cannot be averted entirely, Utah can benefit from experiences elsewhere. California has some of the most restrictive building requirements in the nation due to lessons learned from damaging urban earthquakes. Chile has developed a seismic recovery resilience far stronger than New Zealand's. In evaluating the Japanese experience of the great 2011 Tohoku earthquake, a team of experts assembled by the Heritage Foundation identified four critical factors that affect response to a catastrophe: recovery and resilience of critical infrastructure, environmental remediation, compensation and disaster assistance, and population resiliency.[40] There is a perception that Utah is reasonably prepared for the 72-hour aftermath of a large earthquake, but will it be prepared for years or even decades of recovery and rebuilding?

San Francisco has developed a model framework for improving its disaster resilience: *The Resilient City: Defining What San Francisco Needs from its Seismic Mitigation Policies*.[41] A similar path forward for Utah can be developed. This likely will involve asking questions such as: What does the state need from its seismic-safety policies? What can be done about the dilemma of unsafe existing buildings, particularly URMs, that are privately owned but which pose a public risk? How should we build right the first time to improve seismic performance? Which lifeline infrastructure needs to be upgraded? What planning is needed to ensure the safety of residents who return to their homes after an earthquake?

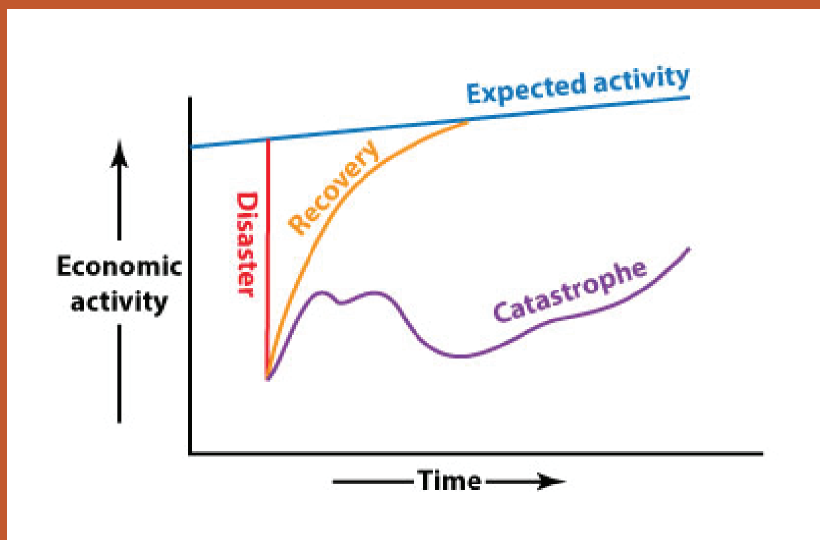
*Engineered residential home with extensive foundation with piles. Other homes around the neighborhood suffered significant damage due to liquefaction - 2011 $M_W$ 6.1 Christchurch, New Zealand earthquake. Photo: EERI/Justin Marshall.*

Discussions are needed about what is "safe enough" for Utah. Planning for resiliency involves concepts such as performance-based design to minimize occupancy disruption; improved construction standards for new and existing buildings; acceptable time frames for recovery of water, sewer, and roadway services; and reasonable recovery rates for businesses and housing needs. These are far-reaching decisions that should involve all who are affected.

The average repeat time of large surface-faulting earthquakes on the Salt Lake City segment of the Wasatch fault is in the range of 1,300 to 1,500 years, and the last one occurred around 1,400 years ago—enough time for strain energy to build up to unleash another. The situation is akin to "Russian roulette": the Wasatch fault beneath the Salt Lake Valley is "loaded" but we don't know whether the next Big One will strike soon or many decades from now.

Given the host of problems that state leaders in Utah face, some will relegate the scenario earthquake threat to the category of "We'll cross that bridge when we come to it." With an estimated $33 billion loss at stake—more than double the state's current total annual budget of $13 billion and comparable to the $32 billion in total dollar assets statewide at risk managed by the Utah Division of Risk Management—then surely prudent risk management calls for serious discussion and contingency planning for an earthquake disaster.

The projected social and economic impacts described in this report can be different and less dire. Collectively and individually we can change this story by making our communities more disaster-resilient and less vulnerable to catastrophe (see box below). But that will take political will, time, and financial investment. To advance Utah's preparedness to withstand, to respond to, and to recover from the next large Wasatch fault earthquake in the Salt Lake Valley, we conclude with nine recommendations to the Utah Seismic Safety Commission.




## Disaster or Catastrophe?

Under normal conditions (blue line), the economic activity in a region will gradually grow with time. When a disaster strikes (red line), assets are lost and many businesses shut down. As power and water service are restored, some businesses reopen, and an influx of insurance payouts and government assistance is used to hire contractors. This can lead to a rapid regeneration of economic activity and a return to economic health within a couple of years (orange line). To an economist, a disaster becomes a catastrophe (purple line) when the regional economy suffers a breakdown in resiliency and sinks into a depression that could last decades. To a sociologist, a disaster becomes a catastrophe when social, economic, and political systems suffer severe disruptions.

Reproduced from Perry, *et al.*, 2008, The ShakeOut Earthquake Scenario—A Story That Southern Californians are Writing, *U.S. Geological Survey Circular 1324*.

# Recommendations to the Utah Seismic Safety Commission

## 1

### INFORM THE GOVERNOR'S OFFICE AND THE UTAH STATE LEGISLATURE

Inform the Governor's Office and the Utah State Legislature of the expected physical, economic, and social impacts of a major Wasatch fault earthquake in the Salt Lake Valley. Emphasize what will cripple the state's recovery and what will prevent a catastrophe. State leaders should be encouraged to form a high-level public/private task force to address, as a priority, the resiliency and post-earthquake recovery of critical infrastructure and vital elements of Utah's economy.

## 2

### INFORM STAKEHOLDERS

Inform public and private stakeholders in local jurisdictions, businesses, school districts, higher education, and neighborhoods of the grim reality following an earthquake. This could occur through press releases, public outreach, and town hall meetings. Provide these stakeholders with short-term and long-term actions they can take to make their response and recovery more efficient. We advise a proactive approach with the news media, helping them write compelling stories about this potential post-earthquake scenario along the Wasatch Front. The after-effects of this scenario earthquake must not be a surprise to anyone.

## 3

### ASSESS THE OPERABILITY OF CRITICAL FACILITIES

Identify critical facilities including schools, police stations, fire stations, and acute care hospital buildings that have risk of inoperability after an earthquake. Establish a long-range plan to improve their post-earthquake operability.

## 4

### PROMOTE POST-EARTHQUAKE RECOVERY PLANNING BY UTILITY PROVIDERS

Encourage every utility (public, private, and municipal) to create action plans that address the issues raised in this scenario report so that they can maintain services or restore them as soon as possible following an earthquake.

## 5

### ADVOCATE SEISMIC RETROFITTING OF VULNERABLE BUILDINGS

Advocate the development of local and state legislation, as well as the necessary funding, requiring mandatory seismic retrofits of buildings that pose a life-safety risk, such as unreinforced masonry and non-ductile concrete structures that are for public use. Encourage local jurisdictions to create incentives for private building owners to increase resilience of their communities through seismic improvements to vulnerable structures.

## 6

### ENCOURAGE ADOPTION OF POLICIES FOR BUILDING OCCUPANCY RESUMPTION

Encourage the adoption of the Building Occupancy Resumption Program (BORP) in all jurisdictions along the Wasatch Front and by the Utah Division of Facilities and Construction Management for state-owned buildings. This program (already adopted by Salt Lake City and Murray City) allows businesses and other building owners to pre-certify inspectors for emergency, post-earthquake evaluation of their facilities—which will enable them to quickly assess their buildings, begin recovery, and resume operations significantly faster.

## 7

### PROMOTE IMPROVEMENT AND APPLICATION OF GEOLOGIC HAZARDS INFORMATION

Advocate continued state and federal support to improve information and maps on earthquakes and related geologic hazards. Promote these tools to the state, counties, and cities for land-use planning, development decisions, scenario planning, emergency response, and recovery planning.

## 8

### ADVOCATE CONTINUED SUPPORT FOR CRITICAL SEISMIC MONITORING IN UTAH

Advocate continued state and federal support for operating and enhancing Utah's regional/urban seismograph network to ensure the availability of critical information for emergency management, emergency response, and future earthquake engineering. In the event of a large earthquake as outlined in this scenario, near-real-time information on the extent and severity of ground shaking will be vital for situational awareness. The ensuing earthquake information products from the network will be needed to guide short-term and long-term recovery efforts.

## 9

### ADVOCATE DISASTER RESILIENCY PLANNING

Use the work done for this scenario to more fully engage stakeholders in developing disaster resiliency plans. This report is a first step that outlines the enormity of what will likely happen in this scenario earthquake, which can serve as a lesson for the rest of the state. What is needed next are plans that will expedite recovery and prevent catastrophe—whether after a large earthquake or any other large-scale disaster.

# Notes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2. Utah Seismic Safety Commission (2008). Putting down roots in earthquake country—your handbook for earthquakes in Utah: http://www.ussc.utah.gov/putting_down_roots.html.

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4. U.S. Department of Commerce, Bureau of Economic Analysis.

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6. Letter by G.K. Gilbert to the Salt Lake Daily Tribune, September 20, 1883 [reprinted in Gilbert, G.K., 1884, A theory of the earthquakes of the Great Basin, with a practical application: American Journal of Science, 3rd ser., v. 27, p. 49–53.

7. Information on the Wasatch fault described in this section has been distilled from various sources. In particular, we refer the reader to DuRoss, C.B., and Hylland, M.D. (2015). Synchronous ruptures along a major graben-forming fault system: Wasatch and West Valley fault zones, Utah: Bulletin of the Seismological Society of America, v. 105, no. 1, p. 14–37 and to references therein. See also Wong et. al. (2013), cited earlier. A major evaluation of available information and data for the Wasatch fault has recently been made by the Working Group on Utah Earthquake Probabilities (WGUEP), under the auspices of the Utah Geological Survey and the U.S. Geological Survey. Information here is consistent with the findings of the WGUEP, whose report is currently in review and expected to be released in 2015. Definition: An active fault is generally considered to be a fault that has moved one or more times in the last 10,000 years and is likely to be the source of earthquakes in the future.

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11. Information on the Salt Lake City segment of the Wasatch fault is summarized from DuRoss and Hylland (2015), cited earlier.

12. From DuRoss and Hylland (2015): The best estimates for the repeat time of large surface-faulting earthquakes on the SLC segment are 1.3 ± 0.1 (mean ± 2σ) thousand years, based on the four paleo-earthquakes since about 6,000 years ago, and 1.5 (1.4–1.8) thousand years, based on the eight paleo-earthquakes since about 14,000 years ago. The most recent large surface-faulting earthquake on the SLC segment is dated at 1,340 ± 160 years (mean ± 2σ cal yr B.P., where “cal yr B.P.” signifies a radiocarbon age date in “calendar years before present,” referring to a reference date of 1950. Thus, this earthquake occurred 1,405 ± 160 years before the year 2015.

13. The estimated value of moment magnitude 7.1 ± 0.2 for characteristic earthquakes on the SLC segment comes from the final report (now in review) of the Working Group on Utah Earthquake Probabilities, described above.

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38. Top three photos courtesy of the Utah Division of Emergency Management. Bottom left photo: “Utah National Guard 141104-Z-QD330-094”, U.S. Army photo by Sgt. Nicolas A. Cloward, https://www.flickr.com/photos/utahnationalguard/15711103051/in/set-72157648721256109, available under Creative Commons License: http://www.creativecommons.org/licenses/by-nc-sa/4.0/legalcode. Bottom right photo: “Utah National Guard 141103-A-MD569-010”, U.S. Army photo by Sgt. Michael Harvie, https://www.flickr.com/photos/utahnationalguard/15706104675/in/set-72157648707287079, available under Creative Commons License: http://www.creativecommons.org/licenses/by-nc-sa/4.0/legalcode.

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## Disaster Resilience

"**Resilient communities** have an ability to govern after a disaster has struck. These communities adhere to building standards that allow the power, water, and communication networks to begin operating again shortly after a disaster and that allow people to stay in their homes, travel to where they need to be, and resume a fairly normal living routine within weeks. They are able to return to a 'new' normal within a few years. They are resilient communities because such a blow from nature remains a disaster, but does not become a catastrophe that defies recovery."

**Seismic resilience**: "the ability of the city to remain safe after a major earthquake. A resilient city is able to contain the effects of earthquakes when they occur, carry out recovery activities in ways that minimize social disruption, and rebuild following earthquakes in ways that mitigate the effects of future earthquakes."

From *The Resilient City: Defining What San Francisco Needs From Its Seismic Mitigation Policies (San Francisco Planning and Urban Research Association, 2009)*