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A Seismic Hazards Overview of the Urban Regions of Nevada: Recent Advancements and Research Directions

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ABSTRACT

Nevada is a large western state in the United States with a seismic hazard that ranges from moderate to high, depending on location. This article identifies priorities to improve estimates of the seismic hazard in the most urbanized parts of the state, specifically the Reno–Carson City urban area of western Nevada and the Las Vegas urban region of southern Nevada. Collaborative task forces are needed to efficiently realize these priorities.

For the Reno–Carson City region in western Nevada, the seismic hazard is high because of strain distributed across several active faults, including normal faults that dip beneath parts of the urban areas. The subsurface geometry and possible connections of these faults remain to be determined. The present large uncertainty in estimates of the slip rates can be reduced by future geological and geodetic studies, including trenching at more than one site per fault and increasing the density of geodetic stations to include multiple stations in the mountain ranges between faults to detect rotations. Adjustments to the ground-motion models for the regional properties of western and southern Nevada could reduce ground-motion uncertainties. Ground-motion simulation research needs an improved 3D velocity model.

The seismic hazard in Las Vegas is lower than in Reno. An expanded geodetic network and continued geological studies of the active faults are needed. Uncertainties in the geometry and activity of the Frenchman Mountain and Eglington faults particularly introduce significant uncertainties into the seismic hazard in the Las Vegas basin. The more distant Garlock and Death Valley faults in eastern California impact the hazard in Las Vegas because the Las Vegas basin amplifies long-period ground motion and prolongs its duration, so reliable simulations from these sources are needed.

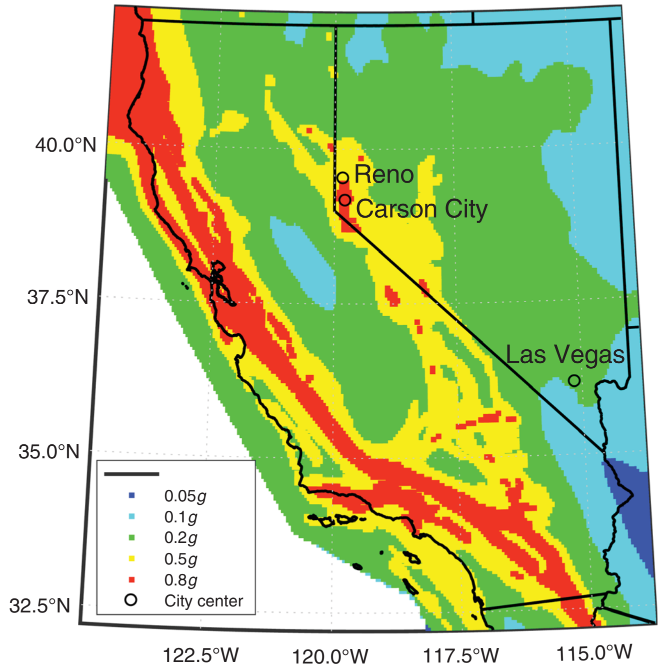
Supplemental Content: Summary of research results presented at the workshop, including expanded discussion of recommendations and references for paleoseismic research sites in the Reno and Las Vegas areas.

INTRODUCTION: NEVADA'S SEISMIC HAZARD

Nevada is a large western state in the United States. The population, with a growth rate of about 2% per year, passed 3 million in 2017. The population is primarily concentrated into the Reno–Carson City urban area of western Nevada and the Las Vegas urban area in southern Nevada (Fig. 1). These urban areas face a high to moderate seismic hazard. A more detailed discussion of the tectonic setting and population at risk is given in the Ⓔ Section S1 of the supplemental content available to this article.

Anderson and Miyata (2006) point out that Nevada has been the second most seismically active state of the lower 48 United States, with historical earthquake rates that are lower than in California but that have easily surpassed the combined rates of earthquakes in the Pacific Northwest states (Washington and Oregon) or the Intermountain seismic zone states (Idaho, Montana, Wyoming, and Utah). The hazard in the Reno–Carson City area is greater than the hazard in most parts of California apart from locations near the San Andreas fault system (Fig. 1).

For the purposes of this article, the Las Vegas urban area includes Las Vegas and associated cities, the largest of which are Henderson and North Las Vegas. This area is entirely within Clark County (2017 population ~2.2 million). The Reno–Carson City area is spread across parts of Washoe, Carson



▲ **Figure 1.** U.S. Geological Survey (USGS) 2014 National Seismic Hazard Model for California and Nevada. This map shows peak acceleration with annual exceedance rate of 4×10^{-4} yr^{-1}, corresponding to the Poisson probability of 2% in 50 yr. The legend gives the lower bound of hazard level for the corresponding color (map created by John Anderson using data from the USGS website; see Data and Resources for reference).

City, Douglas, and Story counties and includes California communities around the shore of Lake Tahoe (2017 population ~0.62 million). Both the Las Vegas and Reno–Carson City areas are popular tourist destinations. In 2017, an estimated 42.2 million people visited Las Vegas, and 5 million people visited Reno.

The 2018 Working Group on Nevada Seismic Hazards (NWG) met in Reno, Nevada, on 5 and 6 February 2018. The purpose of the meeting was to review ongoing earthquake hazard research in Nevada, discuss technical issues related to earthquake hazards in Nevada, and identify priorities for future research that will reduce uncertainties and improve the U.S. Geological Survey (USGS) National Seismic Hazard Model (NSHM). A list of participants and abstracts of presentations from the meeting are available on the website for the Nevada Bureau of Mines and Geology (see Data and Resources). The meeting was funded by the USGS. The purpose of this article is to provide a concise review of the future directions recommended by the participants. A brief review of the current understanding of the hazard, of the data that are available to assess the seismic hazard, and of important outstanding issues that impact the seismic hazard is given in the accompanying Ⓔ supplemental content.

The current generation of hazard maps by the USGS (Frankel *et al.*, 1996, 2002; Petersen *et al.*, 2008, 2014, 2015) incorporated and represented the state-of-the-art summaries of the hazard, so the documentation associated with the USGS maps is a valuable resource. There have been several previous workshops to review research and set future priorities for seismic hazard studies in the Basin and Range Province. These include several organized by the Utah Geological Survey (Lund, 1998, 2005, 2006, 2012, 2015) and workshops in Reno on geodetic and geologic data sets (Briggs and Hammond, 2009, 2011).

Outside of the urban areas, Nevada has been a focal point of extensive studies associated with underground nuclear testing and the seismic hazards at the proposed high-level nuclear waste repository at Yucca Mountain (e.g., Stepp *et al.*, 2001). These studies are outside the scope of this review except to the extent that they have helped understand the processes that affect the hazard in the urban areas.

ELEMENTS OF THE NATIONAL SEISMIC HAZARD MODEL

Active Faults

Major paleoseismology contributions to the NSHM are to identify the location and geometry of active faults and estimate the rupture lengths, magnitudes, slip per event, recurrence interval, and slip rate of the faults, and times of paleoearthquakes (Haller *et al.*, 2015; Moschetti *et al.*, 2015; Petersen *et al.*, 2015). This type of information has also been previously used in the Reno–Carson City area to infer earthquake recurrence rates and develop earthquake planning scenarios (dePolo *et al.*, 1996, 1997). The National Quaternary Fault and Fold Database contains summaries of paleoseismic data but is not updated regularly and lacks up-to-date information in many cases. Ⓔ Section S2.1 includes maps of the faults in the Reno–Carson City and Las Vegas areas and a summary of published research. Based on Wesnousky (2019), only a few faults in western Nevada have been examined at multiple locations, so more work is needed.

Considering the large numbers of faults that contribute to the hazard and need eventual improved characterization, it is essential to prioritize the future studies of these faults. The NWG agreed that the first priority is to better understand the faults that are capable of causing damage in the main urban regions. Considering the existing hazard model (Petersen *et al.*, 2014), deaggregation assessment, and the qualitative evaluation of existing fault information (Ⓔ Table S.4), a set of faults were prioritized for future study; Table 1 identifies these priority fault studies.

Geodetic Studies

On a large scale, as predicted by Kostrov (1974), the geodetic strain rate is consistent with the earthquake occurrence rate in the Basin and Range (e.g., Anderson, 1979; Pancha *et al.*, 2006). Geodesy made major contributions toward understanding the deformation field of the Great basin, Walker Lane, and Sierra Nevada mountains, as summarized in the Ⓔ Section S2.2, and should have an increasing importance in the future.

The geodetic models are limited by the density of geodetic stations. The resolution in southern and eastern Nevada is significantly lower than in western Nevada. More stations are particularly needed to understand the strain field near Las

Table 1
Priority Fault Studies

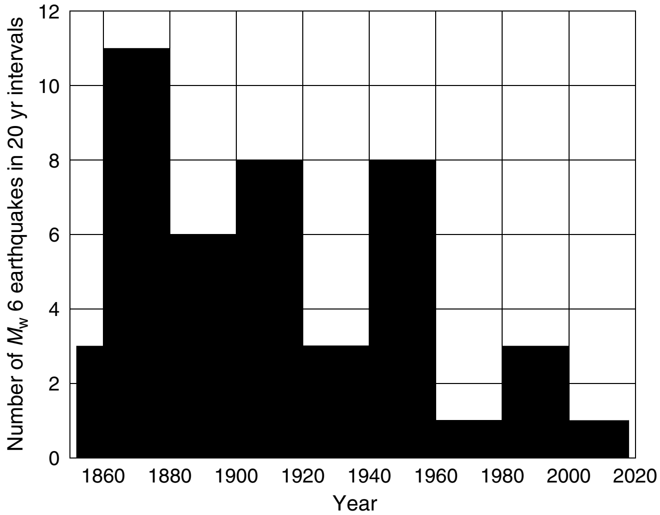
Priority	Fault	Comments and Particular Issues
	Western Nevada	
1	Mt. Rose	Dominates the hazard in Reno from downtown to the southern limits of the city. Need dates and offsets for multiple prehistoric ruptures
		Optimal trench site at Thomas Creek on United States Forest Service land. Multiple sites would be better than just one
1	Genoa system	Dominates hazard for Carson City and Douglas County. Multiple splays at north end are all important
1	Little Valley	Major contributor to hazard of south Reno and Carson City
2	North Valley faults	Particularly relevant north of downtown Reno and the rapidly growing suburbs to the north
2	East Carson Valley	Not in 2014 National Seismic Hazard Model
2	East Reno and central Reno	May be active. Study of geometry of Reno fault system would provide a better understanding
2	North Tahoe fault	
2	Incline Village fault	
	Southern Nevada	
1	Eglington and Las Vegas Valley fault system	Strong impact on Las Vegas hazard. Enigmatic fault system
1	Frenchman Mountain fault	
1	Black Hills fault	
1	California Wash fault	

Vegas and to understand where and how strain is transferred from the Walker Lane to Utah (e.g., Kreemer *et al.*, 2010). In the high-hazard region of western Nevada, the closely spaced faults also can be better characterized with an increased density of geodetic stations. Estimates of slip rates on closely spaced faults are nonunique because of the physics of the problem, so joint inversion of geology and geodesy is preferred. Despite this limitation, because the NSHM uses estimates of slip rates on individual faults whenever they are available, geodetic measurements with a sufficiently dense network can estimate slip rates on faults that are not otherwise characterized, complement geological studies where they do exist, and help identify regions where focused geological studies are likely to be most productive. Because geodetic measurements are quite economical compared with geological studies, they are an important tool for achieving a uniform statewide understanding of the hazard.

As reviewed in the Ⓔ Section S2.2, the geodetic data also find transient strain effects, including long-term transients from past earthquakes (e.g., Hammond *et al.*, 2009). Considering that the geodetic models are based on ~15 yr of data but the hazard maps created by the NSHM are concerned with average seismicity over hundreds to thousands of years, it is essential to understand the full seismic strain cycle to recognize and appropriately incorporate or avoid transients in the long-term probabilistic maps generated by NSHM. Transients are also worth study for possible relevance to shorter-term effects on hazard (e.g., Hammond *et al.*, 2019), which are important to the general public and the emergency response community.

Seismicity Studies

Seismic networks contribute to the NSHM in many ways (Frankel *et al.*, 1996, 2002; National Research Council, 2006; Petersen *et al.*, 2008, 2014). Some of the Nevada contributions are summarized in Ⓔ Section S2.3. The seismic network in Nevada has been able to expand in recent years as a result of regional fire camera deployments in collaboration with federal, state, and local agencies (Smith *et al.*, 2016, 2019; AlertTahoe websites listed under Data and Resources). The systems support early detection and situational awareness during wildfires. The real-time data for seismic monitoring and fire imagery are collected on a privately managed microwave network that, unlike cellular systems, is not subjected to outages, delays, or limited bandwidth. It is arguably one of the most robust seismic networks in the United States. Nonetheless, network coverage throughout Nevada needs improvement to best serve public safety needs. Installation of seismic stations including strong-motion stations at each fire camera is a valuable and obvious way to enhance the network. Critical lifeline



▲ **Figure 2.** Numbers of earthquakes with $M_w \geq 6.0$ counted in 20 yr time intervals. Note that the first and last intervals are incomplete. This figure is based on earthquakes in the catalog used in the 2014 National Seismic Hazard Model (Petersen *et al.*, 2014), supplemented by the USGS online comprehensive catalog through the end of 2017 (see Data and Resources for references).

infrastructure with national significance, including highways, rail lines, electric power transmission, and pipelines, is subjected to hazards that are distributed throughout the state. Especially in southern Nevada, additional instrumentation is needed to keep pace with seismic hazard assessments, earthquake response, and population growth. When combined with the fivefold increase in Nevada's population in the past 40 yr, there is significant new risk in southern Nevada that is not yet factored in to the distribution of seismic stations.

Seismicity maps are shown in Ⓔ Figure S.2. Figure 2 highlights one feature of the long-term history of known Nevada seismicity: apparently the most recent 60 yr have been far quieter than the previous century (see also Ⓔ Section S2.3). All 13 of the historical earthquakes with $M_w \geq 6.5$ occurred in the ~102 yr period ending in 1954. Only 5 of the 44 earthquakes with $M_w \geq 6.0$, 11% have occurred since 1960, but ~15 would be expected if the same number of events was distributed uniformly across the time period of the available history. Ⓔ Section S2.3 elaborates on the hypothesis that the most recent 60 yr are probably the atypical period.

The workshop recognized numerous research needs that depend on seismic network data. These include high-precision locations and focal mechanisms to better understand fault geometries, quantification of stress drop, constraining attenuation properties in Nevada, calibrating the relationship between regional magnitude scales and M_w, and characterization of clusters leading to better public information on the chances that clusters represent foreshocks and are thus of immediate concern for emergency response and the broader public. Because earthquake clusters have the potential to be foreshocks of large events (e.g., Savage and dePolo, 1993; dePolo, 2014), a useful strategy is to deploy temporary instruments, including strong-motion instruments, around major faults affected by significant clusters.

Ground-Motion Studies

Ground-motion prediction equations (GMPEs) are essential to the NSHM but are often the largest source of uncertainty in probabilistic seismic hazard analysis (PSHA). This is the case in western Nevada (Anderson, 2018), so effort should be made to reduce these uncertainties. Observations described in Ⓔ Section S2.4 suggest a need to adjust the current GMPEs for use in Reno and in Las Vegas. Besides targeted studies of wave propagation and attenuation in the region, more data are needed, particularly ground motions on the hanging wall of normal faults because parts of both the Reno–Carson and Las Vegas areas have this geometry.

There are some precarious rocks, that is, old rock formations that could be easily toppled by an earthquake, in widely distributed locations in Nevada (Brune, 1996, 2019). As discussed in Ⓔ Section S2.4, ground-motion records, particularly strong-motion records, from sites of precarious rocks adjacent to normal faults could play a critical role to resolve some inconsistencies between the persistence of these precarious rocks, GMPE models for normal-faulting earthquakes, and PSHA results.

Although the 2014 maps are provided for a uniform site condition, future versions will produce maps for a variety of soft to hard site conditions defined on the basis of V_{S30}, the time-averaged shear-wave velocity in the upper 30 m of the crust. Region-specific proxies could improve estimated ground-motion hazards for different site conditions. The NSHM also plans to estimate the ground-motion amplifications of long-period hazard for well-studied urban basins. This requires knowledge of the deep structure of the basin. Enhanced geophysical exploration is needed in the urban areas, along with effort to systematically integrate all available data into a 3D community velocity model to evaluate and validate the model by comparing synthetic waveforms with earthquake data from midsized earthquakes, and to exercise the model to generate credible synthetic ground motions from potential major earthquakes for the main urban areas.

GENERAL RECOMMENDATIONS

The workshop participants recognized several general objectives that need to be pursued in support of seismic risk reduction in the Intermountain west region. In terms of organization, the workshop called for formation of research task committees, possibly modeled on experience in Utah (e.g., Wong, 2019). The task forces need to include partnerships with subject matter experts to focus on the numerous topics, issues, and research directions that will support enhanced hazard assessment and seismic risk reduction.

A geology, seismicity, and geodesy research task committee needs to work to develop a coherent organized vetted consensus database on the faults in Nevada, summarizing and synthesizing the existing knowledge. For Las Vegas and southern Nevada, this will include making an effort to get all of the faults into the database and onto the map. The long-range goal is the development of geological faulting models for the Reno–Carson and Las Vegas regions that are consistent with geology and geodesy. For the Reno–Carson region, the workshop recognized that the hazard depends strongly on the geometry of the faults and recommended a collaborative project to synthesize what is known from the geology, geodesy, earthquake seismology, exploration seismology, and exploration geophysics.

A ground-motion research task committee needs to improve a community velocity model, evaluate effects of basins and shallow structures, develop proxies for V_{S30} that are appropriate for Nevada, improve understanding of seismic source contributions, and develop well-vetted simulations.

DATA AND RESOURCES

The complete workshop report (2018 Working Group on Nevada Seismic Hazards—Summary and recommendations of the workshop, by Koehler and Anderson, 2018) is available from the Nevada Bureau of Mines and Geology (http://nbmg.unr.edu/geohazards/earthquakes/2018SeismicHazardsWorkshop.html, last accessed May 2019). Population statistics were obtained from the U.S. Census Bureau (https://www.census.gov, last accessed August 2018). The Advanced National Seismic System (ANSS) Comprehensive Earthquake Catalog (ComCat) is available from the U.S. Geological Survey (USGS; https://earthquake.usgs.gov/earthquakes, last accessed August 2018). The National Seismic Hazard Model is accessed from the USGS (https://earthquake.usgs.gov/hazards, last accessed August 2018). The following websites provide access to and information about the AlertTahoe fire camera system (all last accessed on August 2018): http://www.alertwildfire.org/tahoe, https://www.unr.edu/nevada-today/news/2017/alerttahoe-readies-for-2017, https://www.unr.edu/nevada-today/news/2016/alerttahoe-partners-with-tahoe-prosperity, and http://temblor.net/earthquake-insights/hunting-fires-with-cameras-5426.

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