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Loss-Estimation Modeling Based on the 2008 Wells, Nevada Earthquake

by

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ABSTRACT

On February 21, 2008 a magnitude 6 earthquake struck northeastern Nevada and damaged the community of Wells. A federally sponsored loss-estimation computer simulation, HAZUS, was used to make an early approximation of the earthquake's impact. About five hours after the event, and after several HAZUS runs amid an environment of changing estimates of the earthquake's magnitude and location, the Nevada Seismological Laboratory earthquake data were used, and a memo transferred a total economic loss estimate of $2 million to $3 million to the Nevada Division of Emergency Management. The environment of multiple epicenters ranging as much as 13 km in location and multiple magnitudes ranging 0.3 units prompted a sensitivity analysis of HAZUS results to uncertainties in the input parameters (Price and others, 2010). In the initial HAZUS run for the Wells earthquake, the default centroids of census tracts were used as impact locations for the calculations. This works fine in urban areas, but in a rural environment such as that prevalent across much of Nevada, this can lead to a large discrepancy between the location used in the calculation of the losses and the location of the community that is damaged. The initial HAZUS calculation for the Wells earthquake also used the default HAZUS dataset (2000 census data). This loss estimate was about a factor of 3 smaller than the current estimate of actual economic cost of the Wells earthquake, which is approximately $10.5 million.

Two deficiencies in calculating potential losses using HAZUS in Nevada have been overcome by correcting the locations of the centroids of census tracts to the locations of the population centers, and by upgrading the input data set, particularly the public building inventory, for Nevada communities. The results of the HAZUS sensitivity analyses reinforce the operating assumption that HAZUS results are good to a factor of 10, or one order-of-magnitude, and that it is important to communicate this uncertainty in the reporting of the results.

Using the upgraded HAZUS program and the finalized location and magnitude of the Wells earthquake, the total economic loss estimate increased to $17 million; the difference in HAZUS estimates was largely due to the shorter epicentral distance to Wells used in the new calculation. A further improvement in the HAZUS estimate can be made when using ShakeMap (a U.S. Geological Survey (USGS) post-earthquake product produced from a combination of actual measurements of ground motion and modeling to interpolate between seismic instruments). Douglas Bausch (personal communication, 26 February 2010) used the latest ShakeMap for the Wells earthquake to estimate the total economic loss as $12 million. This improved HAZUS estimate is about a factor of 1.1 larger than the current estimate of loss from the earthquake. This is a small difference compared to the order-of-magnitude of uncertainty for HAZUS results.

Overall, our ability to run HAZUS immediately following a major earthquake in Nevada, to understand the HAZUS loss results, and to cast these results into useful perspectives has been greatly improved since the 2008 Wells earthquake.

INTRODUCTION

Immediately after a major earthquake, the Nevada Bureau of Mines and Geology (NBMG) has the responsibility to run the Federal Emergency Management Agency (FEMA)'s loss-estimation model, HAZUS (FEMA, 2003; 2004), and report selected results to the Nevada Division of Emergency Management (NDEM). The NDEM Administrator incorporates this information, along with information coming from the scene of the earthquake, into the process by which the Governor decides whether to declare a state emergency and ask for federal assistance. Based in part on experience from the Wells earthquake, and assisted by FEMA, NBMG has made improvements to the HAZUS program and its procedures for reporting results, which are described in this report. Additional improvements, such as automation of HAZUS, could be made, and further upgrades of ShakeMap input are underway.

RESULTS REPORTED TO THE NEVADA DIVISION OF EMERGENCY MANAGEMENT

Within minutes after the 21 February 2008 Wells earthquake, NBMG's geographic information system (GIS) experts began HAZUS runs. There was initial confusion regarding both the magnitude and location of the earthquake, because the Nevada Seismological Laboratory (NSL) used the EarthScope seismographic stations (part of an experiment funded by the National Science Foundation) that were located in northeastern Nevada and local Richter magnitude in their analysis, whereas the USGS did a regional analysis and used moment magnitude. Within several hours, however, the USGS and NSL had agreed upon their best estimates of the location, a moment magnitude of 6, and the depth of the earthquake. In the meantime, NBMG used NSL's earthquake parameters and completed the official HAZUS run, reporting to the Governor using what turned out to be close to the final location and depth but a magnitude that was 0.3 units higher than the final value. Following NBMG protocols, initial HAZUS results were checked by the NBMG Director before they were forwarded to NDEM (figure 1). Approximately five hours elapsed between the earthquake occurrence and NBMG's report to NDEM.

In reporting HAZUS results to the NDEM, NBMG is careful to remind recipients that HAZUS is a computer simulation, whose calculations are not necessarily an accurate estimate of actual losses. In general, HAZUS provides a "ballpark" or order-of-magnitude estimate, which is perhaps the best than can be expected and nonetheless quite useful (Price and others, 2010).

Now, almost three years after the Wells earthquake, approximately \$10.5 million in total economic losses have been documented. At the time of the event, using the default parameters in HAZUS (HAZUS-MH MR3, Version 1.3, with information on the population and building stock from the U.S. Census Bureau's 2000 census), we calculated a total economic loss of \$3.9 million (location D in table 1); however, uncertainty in the location and magnitude were such that the HAZUS estimate could have been as high as \$6.3 million (Location A in table 1). As discussed below, we believe a major reason for HAZUS' underestimation with regard to the Wells earthquake is its treatment of population distributions.

HAZUS utilizes either block-group (fine-scale) or tract (coarse scale) population figures from the U.S. Census, which are updated only once a decade. Toward the end of a decade, these figures can be surprisingly wrong in rapidly urbanizing areas (not the case in Wells). We have previously reported (NBMG Open-File Report 09-7) on a technique used by NBMG to update the HAZUS population data to 2005 estimates using GIS. Also, HAZUS assumes that the entire population of a census block or tract is located at its geographical center, i.e. centroid. This assumption can lead to significant errors even in rural areas with small populations, particularly for large, unevenly settled census tracts, as is the case throughout much of Nevada. With FEMA's assistance, we have reduced this error by defining tract-level, population-weighted centroids that more closely represent the actual patterns of settlement, hence economic exposure, than do the geographic centroids. This approach could be easily applied in other states.

MEMORANDUM

FROM: **Nevada Bureau of Mines and Geology**
Dr. Jonathan G. Price, State Geologist and Director, and
Jordan Hastings, Chief Cartographer and GIS Manager,
Ronald H. Hess, Chief Information Officer

DATE: 21 February 2008
LOCAL TIME: 11:20 a.m.

TO: Frank Siracusa, Chief Nevada Division of Emergency Management FAX: 687-6788
(Telephone 687-4240, fsiracusa@dps.state.nv.us, kcarmazzi@dps.state.nv.us, rmartin@dps.state.nv.us)

SUBJECT: Information for the Nevada Division of Emergency Management, to be relayed to the Governor and local Emergency Operations Centers, as appropriate

We have run the Federal Emergency Management Agency's computer simulation, called **HAZUS**, which estimates likely losses from earthquakes, given the magnitude, epicenter location, and depth of an earthquake. **The results of this computer simulation are not actual damage or casualty figures.** They should only be used to ascertain the likely severity of the event and assist the State in making decisions regarding deployment of resources to assist local governments in responding to the event. These results have helped other states to decide whether to request a Presidential Declaration of Disaster.

For this magnitude 6.3 daytime event, HAZUS estimated
$2 to 3 million in economic loss,
of which $0.5 to 1.8 million was in building damage,
up to $300 thousand was in damage to building contents, and
up to $600 thousand was in business interruption losses related to the building stock;
Extensive damage to 0 to 5 buildings, moderate damage to 100 to 150 buildings, slight damage to 300 to 400 buildings
Zero to 10 possible injuries

We have used the preliminary calculations of magnitude, epicenter location, depth, and fault-plane solution provided by the Nevada Seismological Laboratory: Magnitude 6.3; Event location: 41.152 latitude; -114.8669 longitude; 6.6 km depth; N48E orientation, 65 degree dip, normal fault.

The Nevada Seismological Laboratory (www.seismo.unr.edu) and the U.S. Geological Survey (earthquake.usgs.gov) will report the locations and sizes of additional earthquakes and accounts of damage from citizens who log onto the Web at http://pasadena.wr.usgs.gov/shake/imw/.

There is a small chance that this earthquake was a foreshock of a larger event; studies of past earthquakes in the region indicate a 6% probability of a larger earthquake in next five days. In addition, aftershocks are common after Nevada earthquakes. Buildings can be weakened by the initial shock and further damaged by aftershocks.

The Nevada Bureau of Mines and Geology (www.nbmg.unr.edu) will be establishing a Post-Earthquake Technical Information Clearinghouse website and will relay information that we collect about the extent of damage to you.

For more information, please contact us by telephone [775-784-6691 extension 5 (Jon Price) or (Ron Hess, 784-6692)], or 682-6352 (Jordan Hastings) or Jon Price at home, 329-8011], fax [775-784-1709], e-mail [jprice@unr.edu, hastings@unr.edu], cell phone [Jon Price at 775-338-7805], or e-mail pager [7753387805@tmomail.net].

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Figure 1. Text of memorandum submitted to the Nevada Division of Emergency Management after the 2008 Wells earthquake.

Table 1. Economic loss and number of buildings with moderate and major damage estimated from HAZUS for four estimated locations, depths, and magnitudes of the 21 February 2008 Wells, Nevada earthquake. These estimates were made shortly after the event but before NBMG updated HAZUS to correct for the geographic location of most people within the census tracts. Compare these results with those in table 2.

Location	Economic losses ($ millions)		Number of buildings with	
	Total	Building-related	moderate damage	major damage
A	6.3	2.1	97	4
B	5.9	2.6	120	6
C	2.8	1.0	55	2
D	3.9	1.0	53	2

A. Location: 41.18 N; 114.86 W; Depth: 8 km; Magnitude 6.3 (NSL's first call at 6:24 a.m.)
B. Location: 41.076 N; 114.771 W; Depth 10 km; Magnitude 6.3 (USGS's first call at 6:30 a.m.)
C. Location: 41.076 N; 114.771 W; Depth 10 km; Magnitude 6.0 (USGS's second call at 7:27 a.m.)
D. Location: 41.1525 N; 114.8669 W; Depth: 6.7 km; Magnitude: 6.0 (NSL's final call).

SENSITIVITY OF HAZUS

Douglas Bausch and Jennifer Goldsmith with FEMA-Region VIII (Bausch, 2009) manually adjusted the HAZUS database to address the census-tract problem in Nevada by moving what HAZUS thinks is the tract centroid to the actual population center within the tract. NBMG now uses a version of HAZUS that incorporates these corrected reference points. Since the 2008 Wells earthquake, NBMG has also updated the database to incorporate new data on critical facilities (Ballard and others, 2009). The results in table 1 were generated in 2008 without this centroid adjustment and using the default input data, whereas those in table 2 have the better locations and the updated critical facilities. HAZUS can also be run using census blocks, which are smaller than census tracts, but running with census blocks would increase the computer time too much for practical use immediately after an earthquake.

Table 2. Economic loss and number of buildings with moderate and major damage estimated from HAZUS for four estimated locations, depths, and magnitudes of the 21 February 2008 Wells, Nevada earthquake. These estimates were made after NBMG updated HAZUS to correct for the geographic location of most people within the census tracts. Compare these results with those in table 1.

Location	Economic losses ($ millions)		Number of buildings with	
	Total	Building-related	moderate damage	major damage
A	26	11	290	97
B	10	4.2	170	25
C	5.2	2.2	100	10
D	17	7.4	220	58
ShakeMap	12	3.1	103	5

A. Location: 41.18 N; 114.86 W; Depth: 8 km; Magnitude 6.3 (NSL's first call at 6:24 a.m.)
B. Location: 41.076 N; 114.771 W; Depth 10 km; Magnitude 6.3 (USGS's first call at 6:30 a.m.)
C. Location: 41.076 N; 114.771 W; Depth 10 km; Magnitude 6.0 (USGS's second call at 7:27 a.m.)
D. Location: 41.1525 N; 114.8669 W; Depth: 6.7 km; Magnitude: 6.0 (NSL's final call).

Whereas the default HAZUS value for total economic loss ($3.9 million) underestimated the current best estimate (approximately $10.5 million), the centroid-adjusted numbers for this earthquake ($17 million) appears to be an overestimate. This may partly be because there was a lack of collateral damage, such as fires, associated with the event and because utility and transportation damages were less than HAZUS modeled (table 3). Because HAZUS should be considered an order-of-magnitude estimator (Price and others, 2010), either HAZUS estimate is a reasonable approximation; the early modeling estimate is a factor of 3 lower than the current estimate, and the improved modeling estimate is a factor of 1.6 higher. A further improvement in the HAZUS estimate was made by Douglas Bausch (personal communication, 26 February 2010) using the USGS's version 14 of ShakeMap for the Wells earthquake rather than the epicenter location, depth, and magnitude. With this improvement, HAZUS estimated $12 million in total economic loss, 1.1 times higher than the current estimate of actual loss (table 2).

A comparison of the HAZUS results from the table 2-location D run, ShakeMap, and estimated values from the actual earthquake is given in table 3. Values were available for only some of the parameters so it is a partial comparison, but it is instructive, nevertheless. The difference in total cost (HAZUS with epicenter input at $16.9 million versus actual loss of approximately $10.5 million in 2008) is mostly from a larger estimate of utility damage in HAZUS than occurred. Fortunately, there was a relatively low impact to most utilities from the earthquake, which helped limit collateral damage and the need for sheltering. There was also little impact on the transportation system from the earthquake, which limited the actual total cost, relative to the estimate by HAZUS. Many of the specific impact numbers reported by HAZUS were close to the actual values, which is reassuring. Note that a "0" result from HAZUS does not mean that there won't be an impact in reality. Although HAZUS modeled "0" schools damaged, "0" police stations damaged, and "0" people needing shelter, in fact there was damage to some of these facilities, and several people sought shelter. Interestingly, the HAZUS estimates using ShakeMap input were comparable to the HAZUS estimates using the best epicenter, depth, and magnitude. Both overestimated utility and transportation damage, but the ShakeMap-HAZUS estimated lower building-related damage (table 3).

Table 3. Comparison of HAZUS results[1] with values from the 2008 Wells earthquake

COSTS (in millions of dollars)

Subject	HAZUS	Actual earthquake	ShakeMap
Building Losses	$ 7.4	>$8.4	$ 3.1
Transportation Losses	$ 2.4[2]	small	$ 2.0[2]
Utility Losses	$ 7.1	>$0.2	$ 7.2
Total Cost	$16.9	about $10.5	$12.4

IMPACT NUMBERS

Subject	HAZUS	Actual earthquake	ShakeMap
Damaged buildings, complete	5	4	0
Damaged buildings, extensive	53	15	5
Damaged buildings, moderate	222	83	103
Damaged schools	0	1	0
Damaged Sheriff/NHP	0	1	0
Damaged Fire Stations	0	0	0
Fires	0	0	0
Injured[3]	3	4	3
Hospitalized[3]	0	0	1
Casualties[3]	0	0	0
Sheltered	0	8	0

[1] HAZUS results used were with upgraded inventory data, the final earthquake parameters, and the centroid adjustment made to the program (table 2, location D).

[2] Douglas Bausch (personal communication, 26 February 2010) noted that the difference between output from HAZUS with or without ShakeMap input and the actual earthquake appears to be due to a possibly overvalued airport building in the HAZUS dataset (Wells Harriet Field valued at $5.9M). Since HAZUS applies an average replacement cost for airport facilities, rural facilities tend to become overvalued.

[3] These values are from the "2 am" run, which corresponds most closely to the early morning earthquake.

In evaluating the sensitivity of HAZUS results to errors in location, magnitude, and depth, Price and others (2010) noted that the largest likely errors for Nevada are in location. Locations can easily be off by 15 km or more. For example, the initial USGS location for the Wells earthquake was off by 13 km relative to the better location that was agreed upon after including data from the EarthScope instruments. Figure 2 illustrates the variation in total economic loss from moving the location of an earthquake like the Wells earthquake. Had the earthquake been directly under the town of Wells, HAZUS would have estimated the total loss to be $35 million.

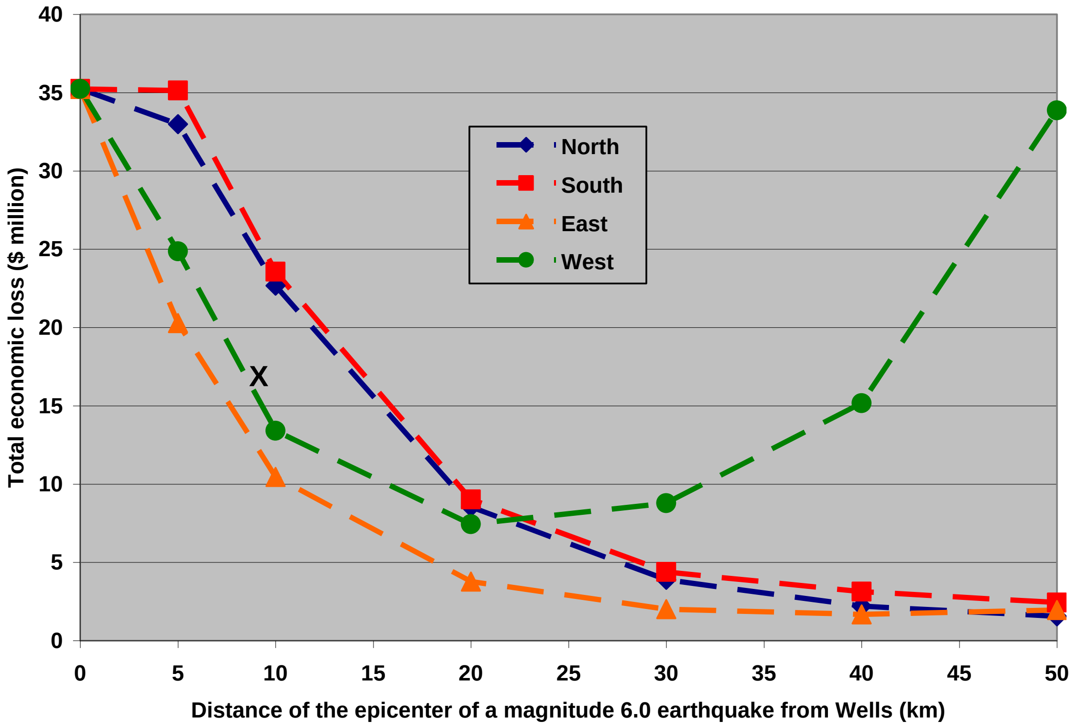

Figure 2. Variation in total economic loss estimated by HAZUS for hypothetical earthquakes of magnitude 6.0 and depth of 10 km at various distances and directions from Wells. The estimate for the epicenter on 21 February 2008, 9 km northeast of Wells, is marked with an X. The western location begins to increase at distances greater than 20 km because it is approaching the community of Elko and causes damage there.

Several HAZUS outputs have been produced to illustrate how HAZUS assigns ground-shaking values geographically and how a 50-km variation in earthquake location impacts these outputs. HAZUS models earthquake shaking using standard ground-motion attenuation models. One of the possible outputs from HAZUS is a contour map showing likely ground shaking (figure 3). Another possible output is a map showing likely ground shaking by census tract (figures 4 through 8). These maps demonstrate how sensitive the ground shaking at a given location is to the distance from the epicenter. The influence of large census tracts (for which the value at the centroid applies to the entire tract) can be seen in comparing figures 3 and figures 4. In this example, with the earthquake located at the population center and the adjusted centroid, a relatively large amount of ground shaking is applied to the entire tract. In examples of more distant earthquakes (figures 5 through 8), ground shaking tends to be low because the hypothetical earthquake is far from the centroids of the census tracts. Figure 2 illustrates how the location sensitivity translates to expected economic loss. With the exception of moving the epicenter to the west (closer to the larger city of Elko), for a magnitude 6.0 earthquake near Wells, damage tends to drop off rapidly within about 25 km of the center of population.

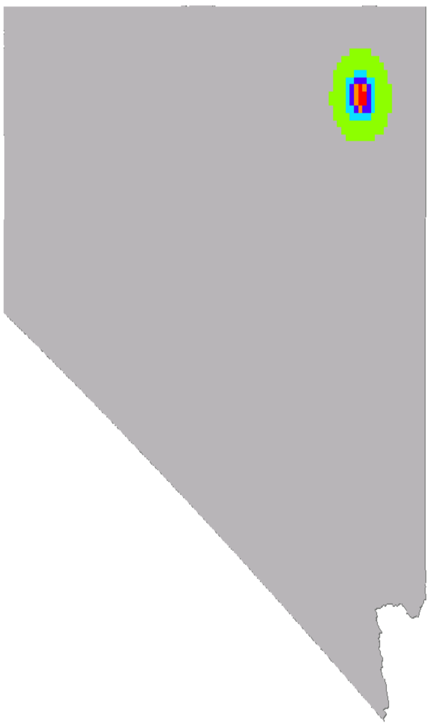

Figure 3. HAZUS output showing expected ground shaking for a magnitude 6.0 earthquake centered on Wells. Colors represent contoured intervals in fraction of the acceleration due to gravity (g) at 0.3 second acceleration. The green zone is 0.10 to 0.22 g; the red zone is 0.54 to 0.65 g. Note that values for colors are different in figures 3 through 8. North is toward the top of the map; the east-west width of the state is approximately 500 km, and the north-south length is approximately 780 km.

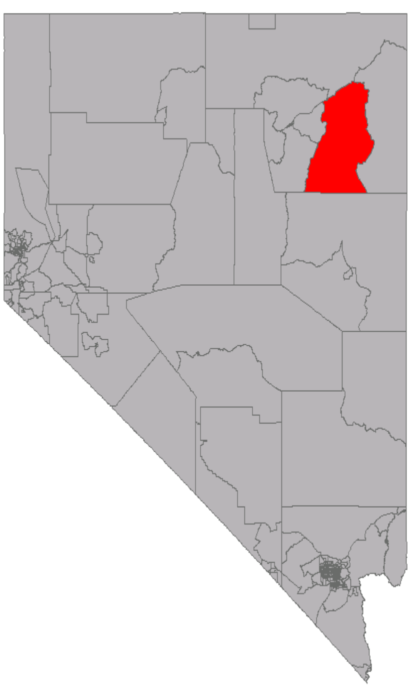

Figure 4. HAZUS output showing expected ground shaking for a magnitude 6.0 earthquake centered on Wells. Colors represent expected ground shaking, in fraction of the acceleration due to gravity (g) at 0.3 second acceleration, for the approximate geographic center of population in the census tract (outlined with dark gray borders). The red zone, covering the census tract in which Wells is located, is 0.54 to 0.65 g. Values in all other census tracts, colored gray, are <0.11 g. Note that values for colors are different in figures 3 through 8.

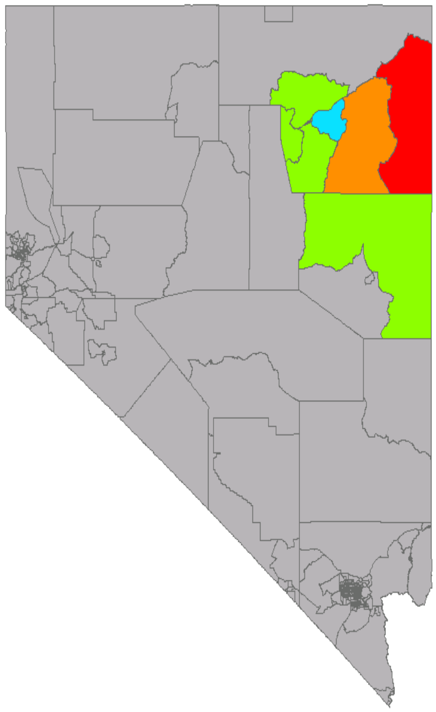

Figure 5. HAZUS output showing expected ground shaking for a magnitude 6.0 earthquake 50 km east of Wells. Colors represent expected ground shaking, in fraction of the acceleration due to gravity (g) at 0.3 second acceleration, for the approximate geographic center of population in the census tract (outlined with dark gray borders). The green zone is 0.02 to 0.03 g; the light blue zone is 0.03 to 0.05 g; the orange zone, in which Wells is located, is 0.07 to 0.08 g; and the red zone is 0.08 to 0.10 g. Values in all other census tracts, colored gray, are <0.02 g. Note that values for colors are different in figures 3 through 8.

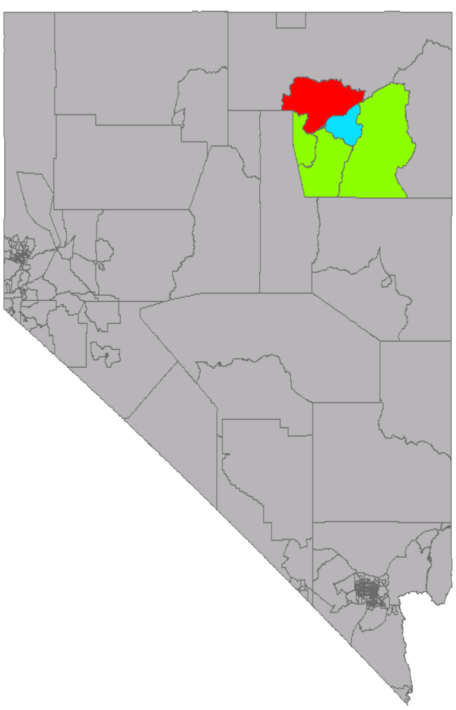

Figure 6. HAZUS output showing expected ground shaking for a magnitude 6.0 earthquake 50 km west of Wells. This event would be affecting the city of Elko more than Wells. Colors represent expected ground shaking, in fraction of the acceleration due to gravity (g) at 0.3 second acceleration, for the approximate geographic center of population in the census tract (outlined with dark gray borders). The green zone, in which Wells is located, is 0.06 to 0.12 g; the light blue zone is 0.12 to 0.18 g; and the red zone is 0.31 to 0.37 g. Values in all other census tracts, colored gray, are <0.06 g. Note that values for colors are different in figures 3 through 8.

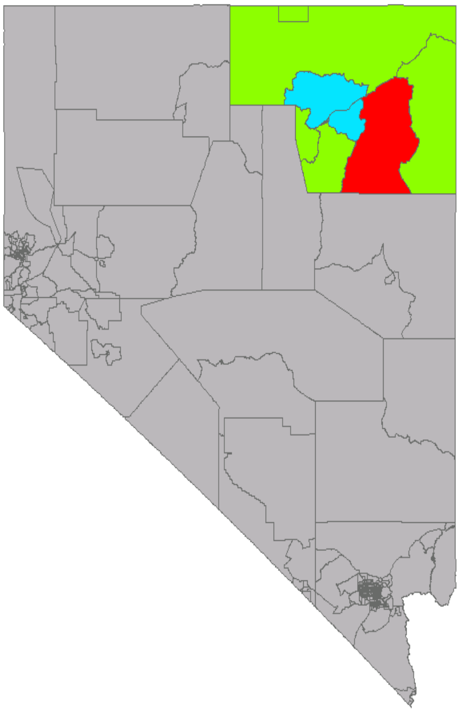

Figure 7. HAZUS output showing expected ground shaking for a magnitude 6.0 earthquake 50 km north of Wells. Colors represent expected ground shaking, in fraction of the acceleration due to gravity (g) at 0.3 second acceleration, for the approximate geographic center of population in the census tract (outlined with dark gray borders). The green zone is 0.02 to 0.04 g; the light blue zone is 0.04 to 0.06 g; and the red zone, in which Wells is located, is 0.09 to 0.11 g. Values in all other census tracts, colored gray, are <0.02 g. Note that values for colors are different in figures 3 through 8.

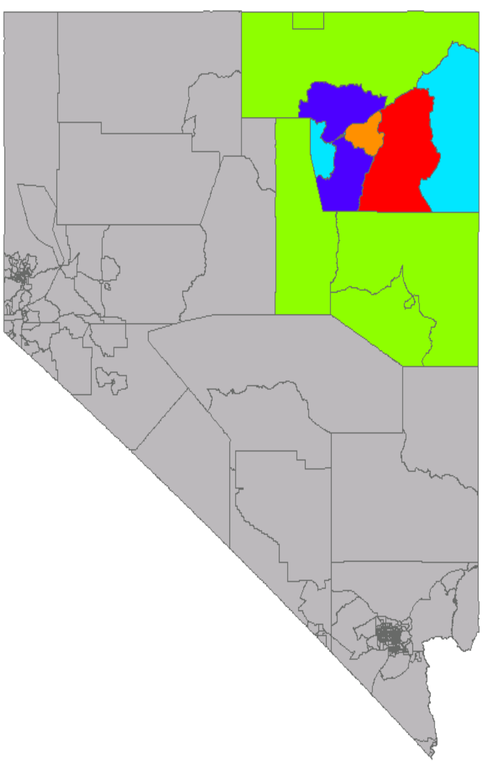

Figure 8. HAZUS output showing expected ground shaking for a magnitude 6.0 earthquake 50 km south of Wells. Colors represent expected ground shaking, in fraction of the acceleration due to gravity (g) at 0.3 second acceleration, for the approximate geographic center of population in the census tract (outlined with dark gray borders). The green zone is 0.02 to 0.04 g; the light blue zone is 0.04 to 0.06 g; the dark blue zone is 0.06 to 0.07 g; the orange zone is 0.07 to 0.09 g; and the red zone, in which Wells is located, is 0.09 to 0.11 g. Values in all other census tracts, colored gray, are <0.02 g. Note that values for colors are different in figures 3 through 8.

In the fall of 2010 the USGS added a simplified loss estimation to its earthquake alerts titled Prompt Assessment of Global Earthquakes for Response (PAGER). These are available online at **http://earthquake.usgs.gov/earthquakes/pager/** and can be sent automatically to anyone who subscribes. The PAGER alerts list estimated fatalities and estimated economic losses in terms of probabilities within order-of-magnitude ranges. For example, probabilities are given for economic loss ranges of zero to <$1 million, $1 million to $10 million, $10 million to $100 million, etc. By using these order-of-magnitude ranges, the PAGER alerts ought to provide information that is comparable to HAZUS results.

RECOMMENDATIONS FOR USING HAZUS FOLLOWING FUTURE EARTHQUAKES

The Wells earthquake taught scientists at NBMG, NSL, and the USGS several important lessons about accuracy of earthquake locations and magnitudes and about use of HAZUS. Several new protocols have been adopted as a result of these lessons, and other improvements will be implemented in the near future. The recommendations for using HAZUS after future earthquakes are enumerated below.

1. Make the official HAZUS run (for transmitting to the Division of Emergency Management and the Governor) on the first location, magnitude, and depth that is checked by a seismologist and reported by the USGS's National Earthquake Information Center (NEIC). Both NSL and the USGS use computer algorithms to automatically calculate locations, magnitudes, and depths immediately after an earthquake occurs, but experience has shown that these automatic picks can sometimes be erroneous. Because NEIC is now a 24-hour-a-day 7-day-a-week operation, there should always be a seismologist there to check whether a given automatically picked event is real or has some problem, such as being an artifact of a larger earthquake at a location elsewhere on the planet. Although this first human-checked pick is not necessarily what will be the final, "official" determination agreed upon by the USGS and NSL, it should be close enough for conveying information as soon as practical about the likely severity of the event. In the first hour or so after an event, knowing whether the damage is likely to be on the order of $10 million or $100 million or $1 billion is quite useful information for emergency managers. Therefore the earliest USGS location and magnitude checked by a seismologist should serve as the input for the official HAZUS run transmitted to the Governor. This is the current protocol used by NBMG.

2. Double check reasonableness of results from the official HAZUS run against the catalog of outputs from previous HAZUS runs and against the USGS PAGER alert for the actual earthquake. Since the Wells earthquake, NBMG used HAZUS to estimate losses from hypothetical earthquakes near 38 Nevada communities, a project that essentially covers all communities with populations over 500 (Price and others, 2009). For each of the 38 communities, we ran HAZUS for earthquakes of magnitude 5.0, 5.5, 6.0, 6.5, and 7.0 at a depth of 10 km and with an epicenter location chosen as the closest point on the Quaternary fault that is nearest to the center of the community. Selected results from these runs, including copies of the global summary reports produced by HAZUS and tables that list selected outputs (total economic loss, number of buildings with extensive to complete damage, numbers of people needing hospital care and shelter, and number of fatalities) are posted online, and an electronic copy is kept by the NBMG Director. Recognizing that ground shaking is attenuated fairly rapidly with distance from the hypocenter of the earthquake, as illustrated in figure 2, this catalog can be used to double check the official HAZUS run. In case the NBMG Director is not available to check the official HAZUS results within an hour after a major earthquake, NBMG Acting Directors should also be trained in using the catalog to check the results.

3. Automate the running of HAZUS at both NSL-NBMG and the USGS-NEIC for the location, depth, and magnitude that are chosen for the official run and using ShakeMap. The California Emergency Management Agency is developing a procedure for automating HAZUS runs. As soon as the computer code is made available, NSL and NBMG should coordinate with FEMA and the USGS to add this code to their systems, so that the first pick of location, magnitude, and depth for a significant Nevada earthquake (magnitude 5.0 or greater) that is checked by a seismologist and reported by NEIC automatically initiates a HAZUS run. Magnitude 5.0 is the lowest magnitude for which HAZUS will work. Given the uncertainties in estimating magnitudes from initial seismic data, consideration should be given to running HAZUS with the assumption that the earthquake is a magnitude 5.0 even when the first seismologist-checked pick is between 4.7 and 5.0. Because a major earthquake in the Reno area could incapacitate NBMG and NSL, redundancy should be built into the coordinated system with the USGS and FEMA by having the NEIC automatically run HAZUS using the same input data (population, infrastructure, and building-stock updates, etc.) as NBMG uses. Attempts are also being made to automate HAZUS runs using USGS ShakeMap results. These should be used by NBMG, NSL, and the USGS, particularly for urban earthquakes where there is a sufficient density of seismic instruments to create a ShakeMap that doesn't rely heavily on modeling to estimate ground shaking.

4. Scientists should wait until ground deformation has been confirmed or until portable seismic instruments have been deployed before assigning an earthquake to a particular fault. We should recognize that earthquake locations, magnitudes, and depths may be fairly inaccurate. For example, the first official report on the Wells earthquake that was issued from NSL (at 6:24 a.m., eight minutes after the 6:16 a.m. mainshock) listed a local magnitude of 6.3 and a location 12 km northeast of Wells, whereas the first official report issued by the USGS (at 6:30 a.m.) listed a body magnitude of 6.3 and a location 17 km east-southeast of Wells. At 7:27 a.m., the USGS revised the size to a moment magnitude of 6.0, but with the same location. In the final analysis later that afternoon, the NSL and the USGS agreed on the NSL's revised location (9 km northeast of Wells, depth of 6.7 km) and the USGS's magnitude (6.0). In the meantime, however, the USGS had compared its initial location with its fault database (USGS, 2009) then issued a website release that put the earthquake on a known Quaternary fault along a mountain range well to the southeast of Wells. Such information can potentially mislead immediate post-earthquake reconnaissance and studies. Based largely on aftershock data from NSL's rapidly deployed portable network and confirmed from geodetic data, the Wells earthquake was on a fault that was not in the USGS's database as a Quaternary or potentially active fault, and no surface ruptures were noticed by NBMG geologists or others.

5. Improve the data in HAZUS regarding such factors as infrastructure, building stock, and population, and improve the input into HAZUS, particularly to take into account actual measured ground motions. The work of Ballard and others (2009) has updated HAZUS to 2005 population estimates and with improved information on critical facilities (hospitals, schools, fire stations, etc.). A project, funded partially by FEMA and the Nevada Public Agency Insurance Pool, is underway to improve HAZUS with data from county assessors; this project will specifically identify probable unreinforced masonry buildings in Nevada communities, which are often the worst performing structures during earthquakes.

Two significant improvements should be made to the input to HAZUS. First, use ShakeMap as input to HAZUS. ShakeMap can be further improved by using information about shear-wave velocities in the near-surface materials to estimate ground shaking between sites where actual measurements are made. Second, HAZUS can be improved by mapping the distribution of National Earthquake Hazard Reduction Program soil types, which can be determined from measurements of shear-wave velocities. NSL and FEMA have efforts underway to measure shear-wave velocities in the urban areas of Las Vegas and Reno, and NSL and the USGS have deployed strong-motion instruments in these areas as part of the Advanced National Seismic System (ANSS). More can certainly be done to bring the geographic density of ANSS instruments up to the full operational level described in USGS strategic plans, and more can be done to model the relationships between measured shear-wave velocities and geologic formations. By also integrating ground-water level data with the geology and velocity measurements, scientists can better estimate liquefaction potential.

The presence of EarthScope seismometers in Nevada at the time of the Wells earthquake and the difference between locations provided by the USGS (without the EarthScope instruments) and NSL (with them) illustrate the need for a more dense network of seismic instruments in Nevada, particularly in areas, such as most of eastern Nevada, where the coverage is sparse to nonexistent. Additional improvements in determining earthquake locations, magnitudes, and depths could also be made through more detailed three-dimensional velocity models based on interpretation of seismograms from past earthquakes, mine blasts, and other explosions. Ideally, there would be at least one strong-motion seismometer, with continuous, real-time telemetry to NSL and the USGS, in every major community in Nevada.

CONCLUSION

HAZUS is a powerful computer model for estimating losses from natural disasters. It has been quite helpful in earthquake-scenario development, emergency planning, and mitigation. The use of HAZUS immediately following the 2008 Wells earthquake as well as subsequent improved HAZUS runs and studies have all confirmed that modeled results are within an order-of-magnitude of the actual effects of the earthquake in Wells. Our understanding of the HAZUS results for Nevada and our confidence in using these modeled results and their potential uncertainties have significantly increased because of these studies. Further enhancement of the input databases and (hopefully) automation of HAZUS are planned for the future.

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