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Modified Mercalli Intensity Maps for the February 21, 2008 Wells, Nevada Earthquake

by

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ABSTRACT

Two Modified Mercalli Intensity (MMI) maps were developed to illustrate the effects of the 2008, magnitude M_w6, Wells, Nevada earthquake. These maps were based on the U.S. Geological Survey's (USGS) Did-You-Feel-It data set, first-hand observations, damage accounts, media accounts, and reports. A map of the MMI in Wells was created by examining the effects at individual houses and buildings; this map shows a pocket of Intensity VIII in the historical district of town, where older buildings collapsed and partially collapsed; a zone of MMI VII in the northern half of the town, where many chimneys were damaged; and MMI VI+ for the rest of town, where widespread non-structural damage occurred. For the regional MMI map, multiple reports were combined for Nevada communities, and the largest, most-common value was used to represent a location. This map shows the areas of MMI VI, V, IV, III, and part of the MMI II area. The distributions of intensity reports for surrounding Nevada communities were compiled with most communities having small ranges in intensity because of limited reporting. Larger communities in the MMI IV area had distributions spanning as many as seven intensity levels. These MMI maps are similar to those generated from reports of damage by other historical magnitude 6 (approximately) earthquakes from Nevada, although these tend to have smoother contours. They complement and compare favorably with the USGS Community Internet Intensity Maps. The MMI maps create a useful graphic visualization of the shaking extent of the Wells earthquake for purposes such as earthquake scenarios and public awareness.

INTRODUCTION

At 6:16 a.m. PST (Pacific Standard Time) on February 21, 2008, northeastern Nevada was struck by a moment magnitude 6.0 earthquake, centered about 9 km northeast of the City of Wells. Severe damage occurred in the historical district of the community and moderate damage (e.g., chimney damage) occurred over about half of the city. In the rest of Wells and surrounding areas, building damage was generally limited to cracks in interior and exterior walls, but dislocation and damage to nonstructural contents were widespread and ranged from slight to extensive. Moderate to strong shaking from the earthquake was felt in northeastern Nevada, northwestern Utah, and southernmost Idaho, and some movement was felt as far away as Las Vegas, Nevada and the Sacramento Valley in California.

The goal of this project was to make Modified Mercalli earthquake intensity maps to illustrate the pattern and distribution of the earthquake's shaking levels based on people's perceptions of shaking, structural and nonstructural damage. These intensity maps, while somewhat imprecise and uncertain because they are influenced by human subjectivity, do show the general distribution of ground shaking and include factors such as geologic effects due to the substrate that influence shaking levels from an earthquake. Modern intensity maps also help us constrain the sizes and locations of pre-instrumental earthquakes which didn't have directly measured magnitudes (e.g., Bakun and Wentworth, 1997). This study creates two intensity maps and displays intensity distributions for Nevada communities from the 2008 Wells earthquake. These maps show areas of a certain level of shaking intensity, separated by "isoseismal lines," which are the approximate boundaries between these areas.

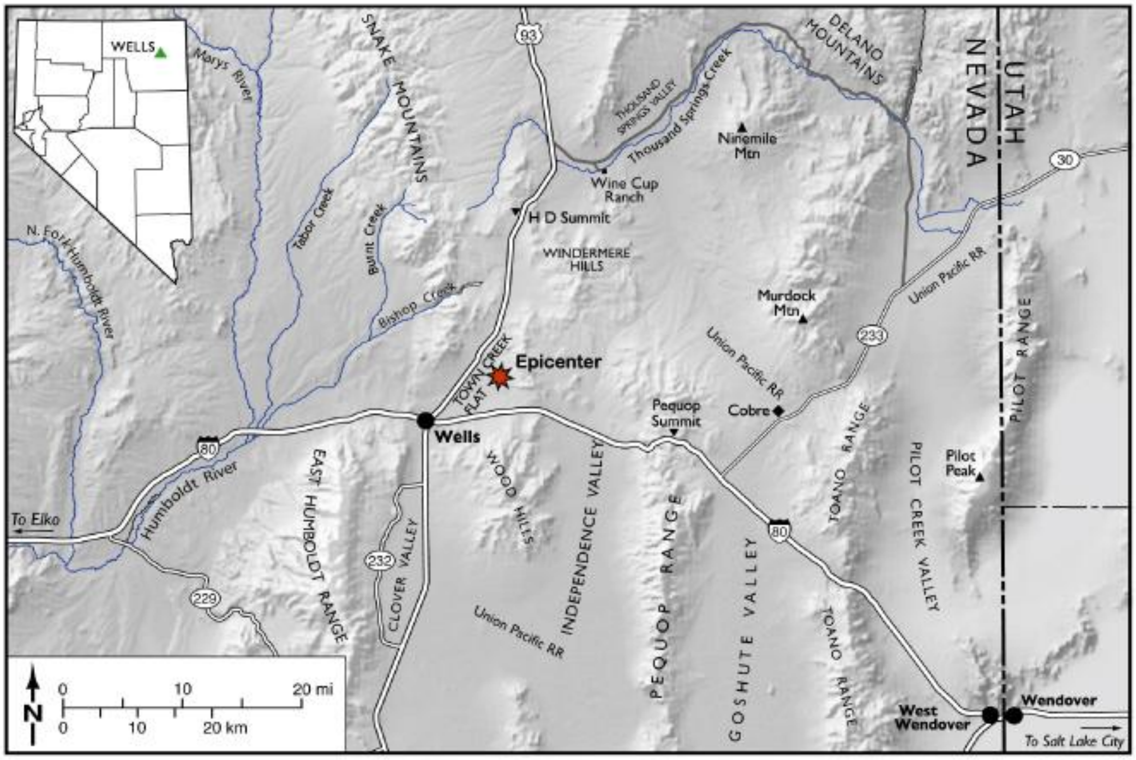

Figure 1. Location map of the epicenter of the 2008 Wells earthquake in northeastern Nevada.

MODIFIED MERCALLI INTENSITY

The Modified Mercalli Intensity (MMI) scale was used to characterize the 2008 Wells earthquake. Originally developed by Wood and Neumann in 1931, the MMI scale has been widely used in the United States since that time. The scale has been modified occasionally to enable it to address effects from both older historical earthquakes and more contemporary earthquakes (e.g., Richter, 1958; Toppozada and others, 1981; Dengler and Dewey, 1998; dePolo and Garside, 2006). Appendix 1 at the end of this paper shows the MMI scale, slightly modified from dePolo and Garside (2006). Intensity values are represented by Roman numerals to distinguish them from other earthquake values, such as magnitude.

The lower part of the MMI scale (I to V) is based on human perception of the shaking and minor earthquake effects. The middle of the scale (VI to IX) describes increasing levels of earthquake effects and damage. The higher end of the scale (X-XII) describes different levels of ground disruption and destruction that would be found near a fault surface rupture, where widespread liquefaction disrupts the ground, or in the near-field shaking zone (where extremely strong shaking occurs). Intensities from the Wells earthquake were in the lower and middle parts of the MMI scale (I-VIII).

Intensity values are influenced by many factors, including distance from the earthquake source, local ground conditions (softer ground is less rigid and can move more easily than harder ground or rock), the nature and condition of the buildings, and the sensitivity and constitution of the people experiencing the shaking. Thus, assigning MMI values to a set of responses and effects at a location can range from relatively straightforward to uncertain and judgmental. There can be several different intensity values for a single location. In many cases, multiple intensity values at a location must be evaluated and combined, requiring an approach that represents a community with a single intensity value. The approach used in this study is presented in the section on the intensity maps for Wells. Even though we represent communities with a single value on the regional map, the distribution of MMI values for Nevada communities from the 2008 earthquake is presented in appendix 2 at the end of this paper.

Community Internet Intensity Map

The Community Internet Intensity Map (CIIM) is created from an Internet-based questionnaire and is particularly useful immediately following an earthquake when information is preliminary and sparse, yet people can report on what they just felt and the effects they can see around them, and Internet systems tend to stay up even though other communication systems fail. The CIIM map was developed by the U.S. Geological Survey (USGS) and gives one of the first impressions of the scope and extent of an earthquake shortly after the event. The questionnaire is called “Did-You-Feel-It?” (DYFI) and the results are used in calculating an intensity value for the CIIM (Wald and others, 1999; USGS, 2004). The results are displayed on the USGS DYFI earthquake web site, with intensities commonly displayed by zip code areas (e.g., figs. 2 and 3) or as geocoded data. A primary part of the data for the regional intensity map produced in this study was the reviewed DYFI information.

Three CIIM maps of the 2008 Wells earthquake are shown in figures 2, 3, and 4. Figure 2 is a zip-code-area map of the approximate maximum number of entries. Figure 3 is a zip-code-area map of the final number portrayed after filtering out false and unreliable entries, and figure 4 is a geocoded map of the same data. Figure 2 was made about a month and a half after the earthquake, when most responses were in (3047 entries). The map gives an idea of how much of the surrounding area was affected by the Wells earthquake and, overall, compares favorably with the regional intensity map produced in this study, but they are different portrayals of nearly the same data. The final portrayals of the DYFI data after clean-up are shown in figures 3 and 4. These have similar extents as earlier versions but a few of the zip-code areas have dropped out. The geocoded version (figure 4) helps one to view the DYFI data in greater detail than in the zip-code area version where zip-code areas are large (rural areas). The geocoded version also portrays the local higher intensity and shows the gaps in the reporting data better.

Figure 5 illustrates the rapid nature of responses to the DYFI Internet questionnaire. Within 8 hours, over half of the total entries were made, which fortunately is when people’s memory is the clearest (over 3,000 total DYFI entries were submitted and about 1,900 entries were used for the final). Entries made to the DYFI after about a month began to include aftershock descriptions and were prone to inconsistencies or inaccuracies.

Intensity Maps for the 2008 Wells Earthquake

We made a local intensity map of Wells and a regional intensity map to illustrate the shaking effects from the Wells earthquake. In this section we discuss the intensity data, our methods for combining data for individual communities, and generating the maps.

Intensity Data

MMI values were estimated using the DYFI data set combined with additional accounts and observations of the earthquake’s effects. Our local MMI map for Wells was mostly based on first-hand observations by the lead author, whereas the statewide map is mostly based on the DYFI data. Other observations from newspapers, reports, and a few insurance assessments were also considered in both maps.

The DYFI data set for the Wells earthquake was provided by David Wald of the U.S. Geological Survey, with the names and addresses removed for privacy. We reviewed these data, adjusted some intensity assignments as necessary (discussed below), and sorted them by community. The entries for each community or location were analyzed and combined to produce a single intensity value to represent a community. Only entries made within the month following the earthquake were used, which allowed for rural communities to report, but helped limited entries that were confused with aftershocks, etc. The locations that were provided with the data set were the centroids of the zip codes. We reassigned the entries to be at the coordinates of the indicated communities or other specific locations. Several entries were discarded because there was not enough information to get a location, they were incomplete, or they appeared to be false reports.

We reviewed the DYFI data for Nevada for authenticity and quality, and in some cases, adjusted or disregarded the values similar to those used in Dewey and others (2002) for the 2001 Nisqually, Washington earthquake. The focus was on assigning intensities to the DYFI information with the intensity descriptions in appendix 1 at the end of this paper. Assigning MMIs (rather than calculating CIIs) lowered some of these intensity values by one intensity unit, mostly rounding down values that were rounded up in the CIIM analysis. In several of these cases, long durations of shaking, perhaps created by basin entrapment of seismic waves, seemed to elevate the CIIM estimates above the description of their effects. Because values are combined for communities, adjustments of individual reports had a minimal overall effect on the final intensity values.

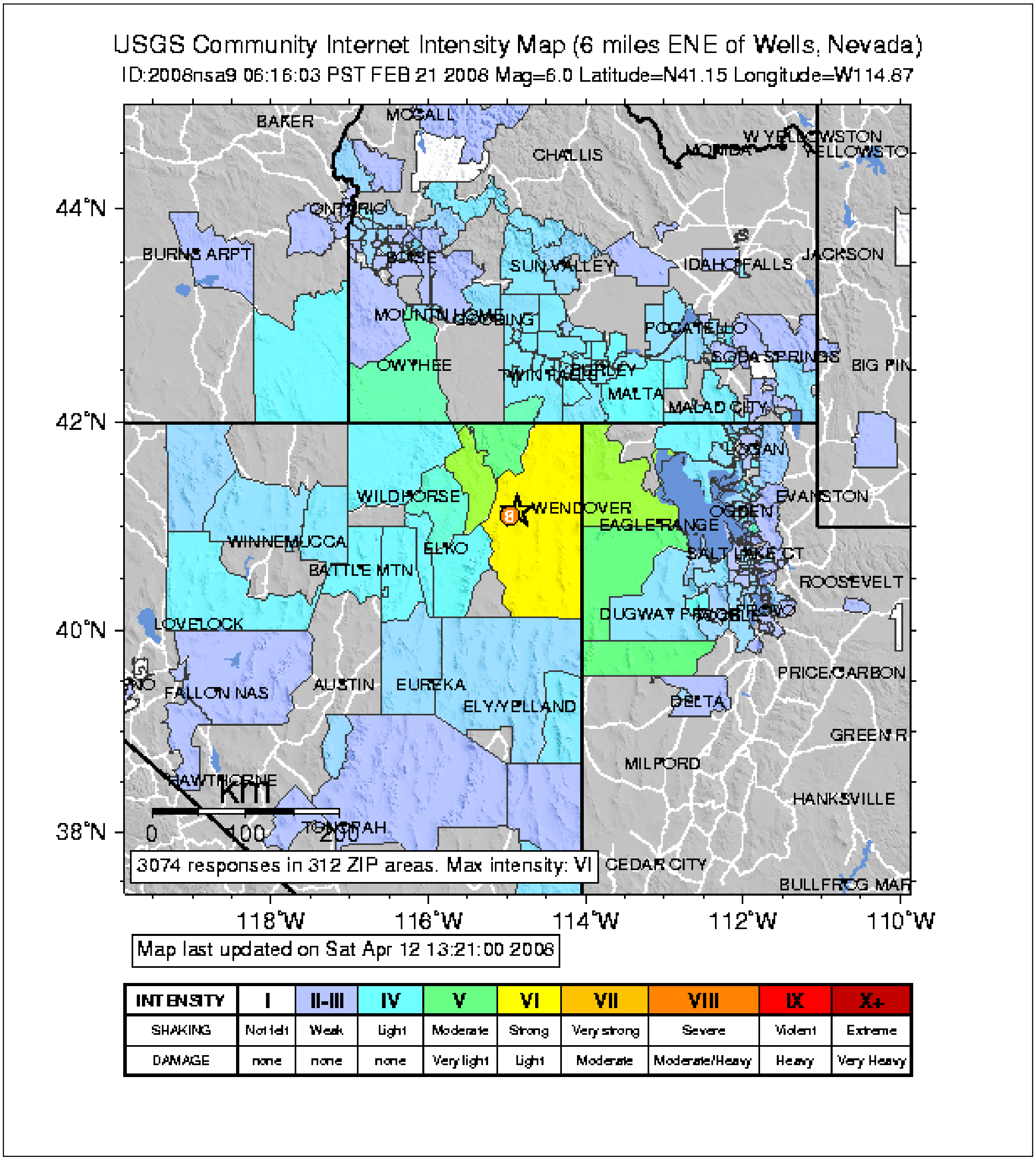

Figure 2. Community Internet Intensity Map for the Wells earthquake as of April 12, 2008 (taken from the USGS DFYI web site on the 2008 Wells earthquake). There were limited responses from rural Nevadans and apparent reporting gaps appear in several counties. The extent of strong shaking can be viewed with this map. This is invaluable information in the time immediately following the event, when detailed information is sparse and uncertain. The maximum intensity (VIII) is indicated with the number in a circle.

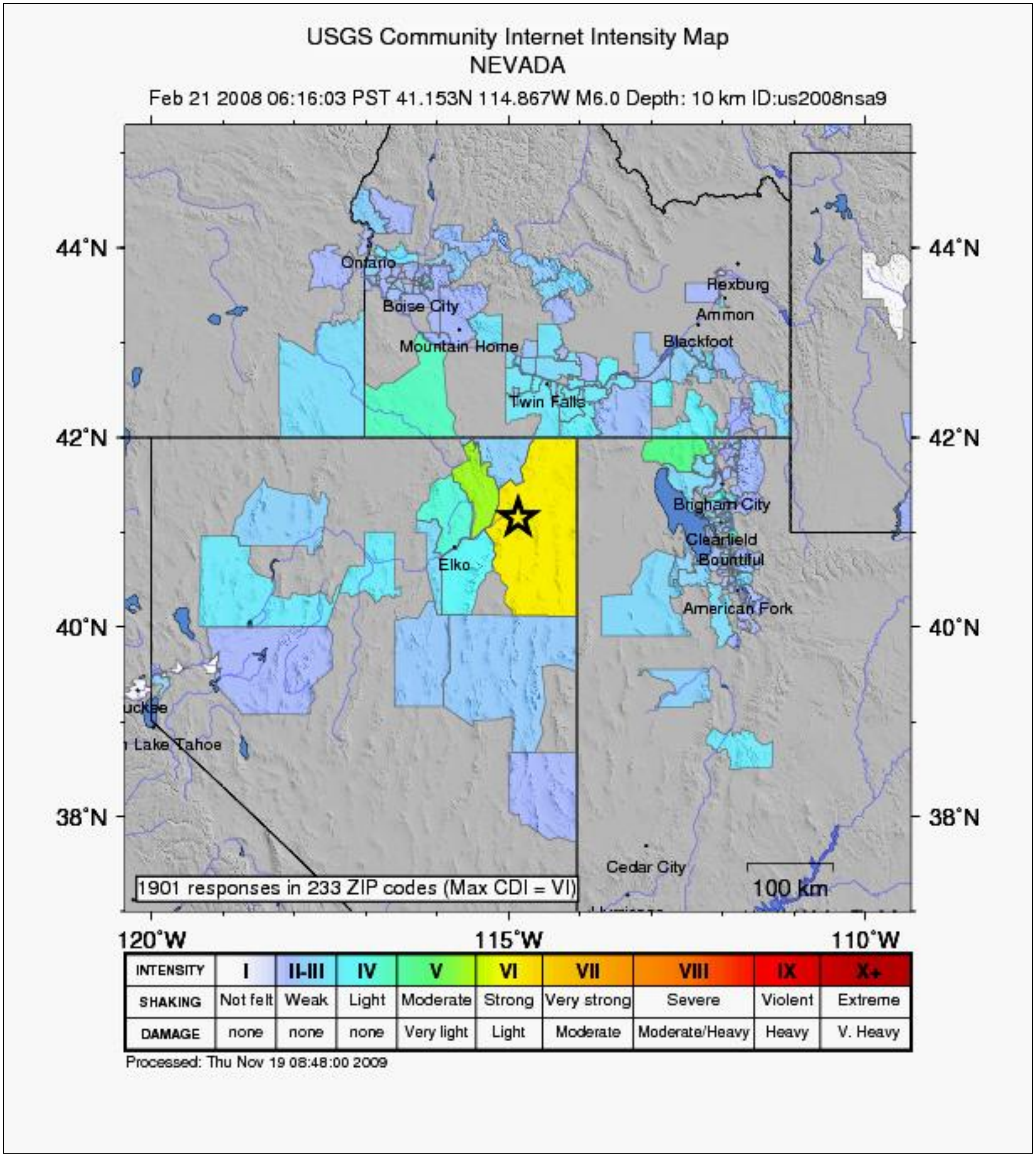

Figure 3. Community Internet Intensity Map for the Wells earthquake created November 19, 2009 (taken from the USGS DFYI web site on the 2008 Wells earthquake). About a third of the entries have been filtered out for the final CIIM map presented on the web. Although the map is sparser looking than the April 2008 version (figure 2), the overall pattern is similar.

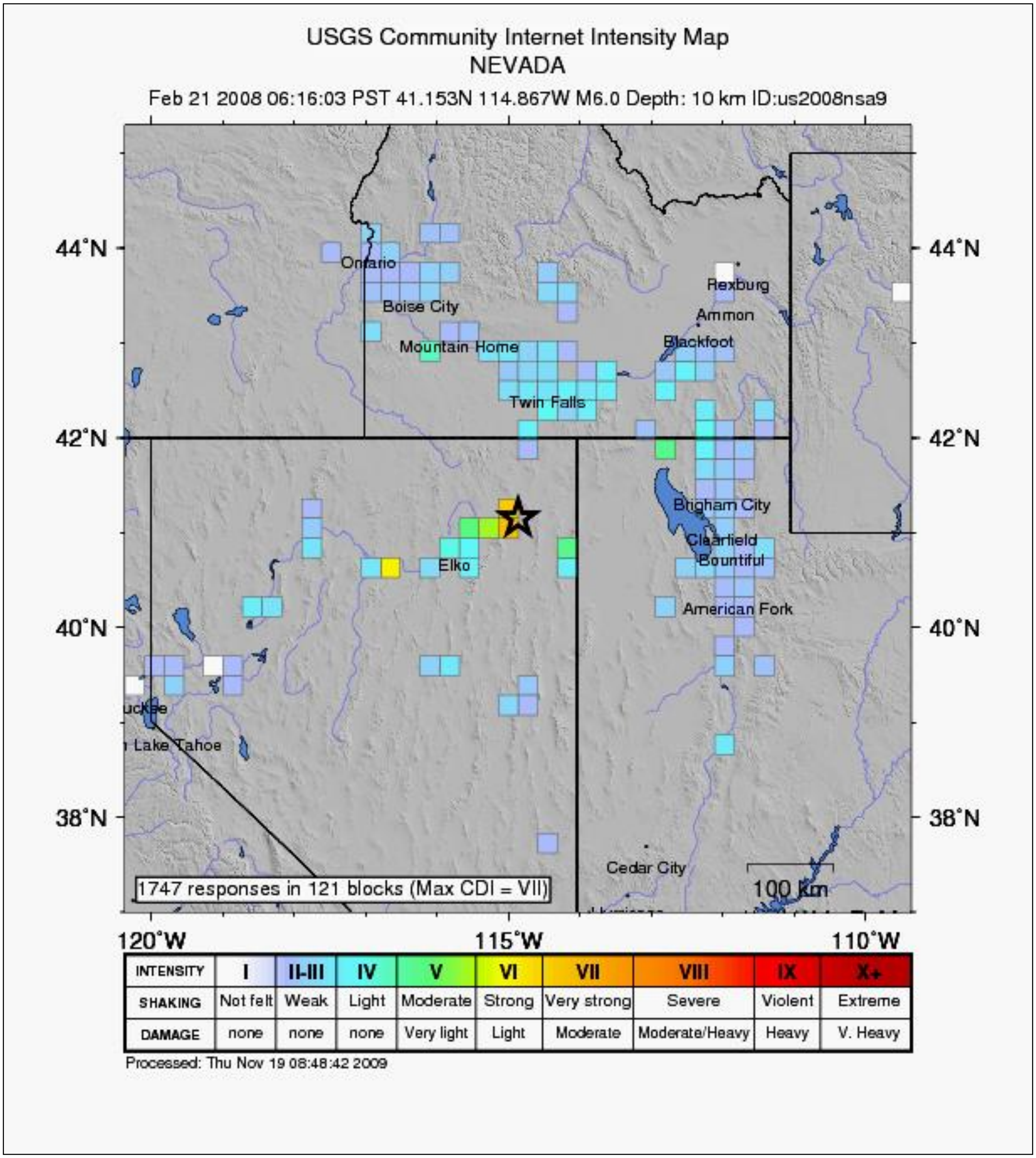

Figure 4. Geocoded Community Internet Intensity Map for the Wells earthquake created November 19, 2009 (taken from the USGS DYFI web site for the 2008 Wells earthquake). This map shows the locations of the responses and gaps in Internet data in more detail versus the zip code portrayal, but is incomplete because not all entries could be geocoded.

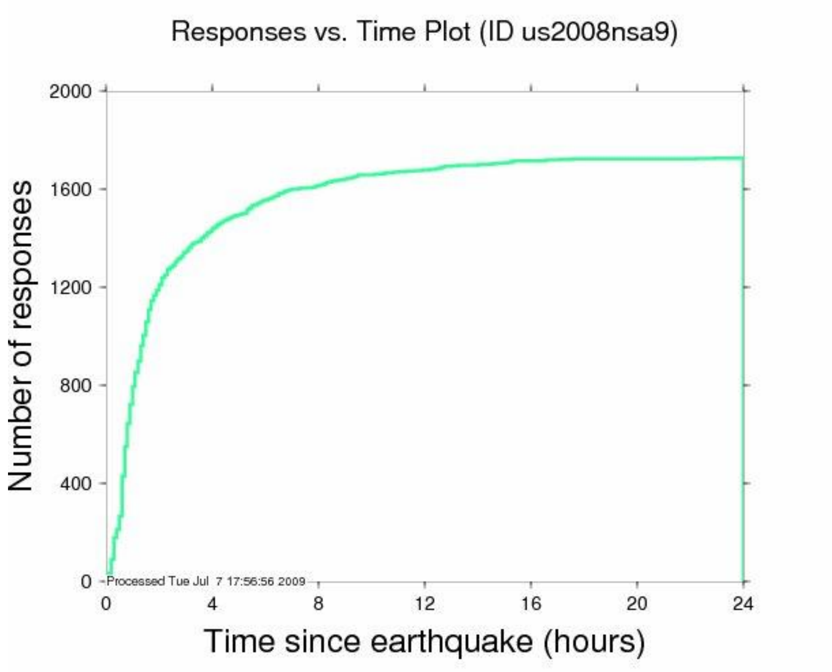

Figure 5. Response-Time history for the Did-You-Feel-It survey following the Wells earthquake showing the large number of responses (over half of the total) that came in within the first 24 hours (taken from the USGS DYFI Web Page on the 2008 Wells earthquake).

In Nevada, there were 410 DYFI responses used for 49 locations. The number of individual responses from communities ranged from 1 (many communities) to 119 (Elko). There were 21 responses from Wells; it is assumed that there were not more responses from an area that shook so strongly because people were dealing with the earthquake's effects and didn't have the time or inclination to go online and fill out a questionnaire. Thus, proactive canvassing of earthquake damaged areas was needed to document the distribution of shaking effects.

Many first-hand observations of Wells and the surrounding area were made by the lead author (dePolo) in the days and weeks following the earthquake. In this process, gaining a caring rapport with the local population helped in understanding what happened inside homes and businesses, beyond what is visible from the road. Printouts of Google Earth® images of Wells at a block level were useful to keep track of damaged chimneys and helped in drawing isoseismal lines.

Assigning Intensity and Drawing Isoseismal Lines

The approach used for assigning intensity values was to seek the highest values that were common in a community or at a location. After the number of reports for each intensity value was compiled, a distribution was drawn for each community (e.g., figure 6). The most numerous intensity values were usually in the central part of the distribution; these are considered to be the most commonly experienced values. The largest intensity from this central part of the distribution was used to characterize a community because there was good confidence that this level of MMI had occurred there and that this intensity level was relatively common. Outlier intensity values were ignored and were assumed to be influenced by variables that were not representative of the overall community. An example of using this approach to combine intensity values for Elko, Nevada is shown in figure 6; here the central part of the distribution is MMI III and IV, and the largest most-common value is MMI IV.

For broader distributions, a simple test was devised so as not to miss important data and to check whether a higher intensity value should be considered. The test considered the number of reports for the next higher intensity value versus the number of reports for the largest most-common value. If the next highest value's number was over half the number of reports of the largest most-common value, the higher intensity was used; only a few sites had increased intensity values because of this test. If a higher intensity value was chosen because of this test, the test was rerun, but no intensity values were adjusted more than once. The final values used were felt to be the largest representative intensities for communities. The final intensity values used are presented in appendix 2 at the end of this paper (Nevada data) and on the regional map (figure 10).

The intensity values for the communities were plotted on maps and isoseismal lines were drawn to divide the different intensity areas. The isoseismal lines are solid where they are reasonably constrained and are dashed where they are poorly constrained, unconstrained, or inferred. Nevada is made up of isolated rural communities in its northeastern part, leading to large distances between intensity reporting sites. In most parts of the map there is a wide area where the isoseismal lines could be drawn. Isoseismal lines were commonly placed conservatively, tightly encompassing data points. The higher intensities (IV-VI) tend to be better constrained than the lower intensities (II and III).

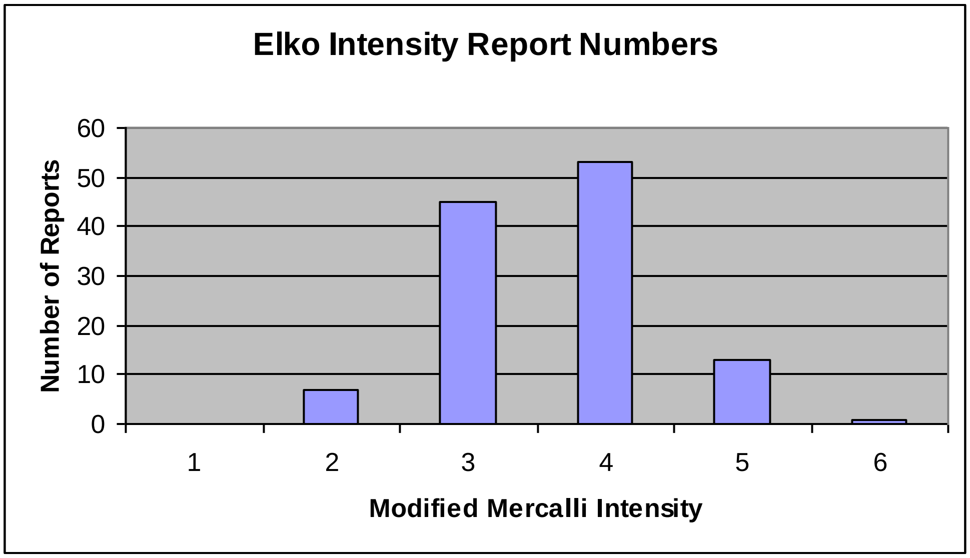

Figure 6. Histogram showing the number of DYFI reports for each intensity reported for Elko. The largest, most-common value assigned to Elko was intensity IV.

Modified Mercalli Intensity Map for Wells

The local MMI map of Wells (figure 7) shows three intensity areas, VI, VII, and VIII. The highest intensity area, MMI VIII, is in the older part of Wells where many historical buildings are located (figs. 7 and 8). Many of these buildings had been abandoned for decades and had fallen into disrepair. In this area, a few buildings partially to totally collapsed, and parapets and the upper parts of brick walls were broken up and fell from several buildings. Most chimneys were shattered in their upper parts.

The northern part of Wells is assigned an intensity of VII, with many broken and fallen chimneys, some broken walls (e.g., figs. 9 and 10). The most dramatic damage in this area was to Wells High School, which sustained structural connection failures and delaminated block walls. In a pocket of intensity VII near the freeway, a water main ruptured, and there was significant nonstructural damage to ceiling systems in stores and content loss. In the intensity VII area, there was some minor panic and some people ran out of their homes. People were very frightened to extremely frightened, with at least one woman having an anxiety attack from the event and needing some medical assistance. The intensity was not mapped beyond Wells because of insufficient data, but the similar shaking intensities were likely felt throughout Town Creek Flat (the small valley Wells is located in).

In intensity VI areas, the earthquake was strongly felt and there was widespread, but highly variable, nonstructural damage and content dislocation (figure 11). Everyone clearly felt the earthquake, was awakened if sleeping, and was startled by its strength. A large bang was heard near the beginning of the shaking by most people in Wells. The duration of shaking was reported to be 20 to 40 seconds.

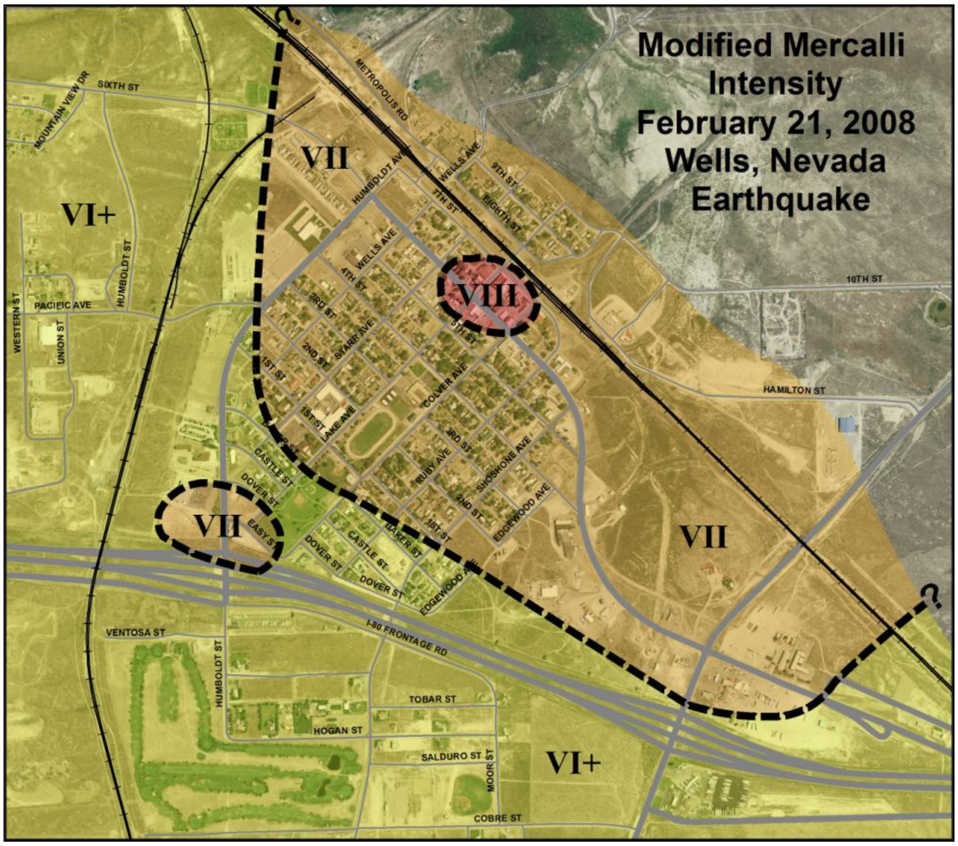

Figure 7. Modified Mercalli Intensity Map of Wells. This isoseismal map of Wells was overlain onto a photograph of Wells that was provided by the Nevada Department of Transportation. General intensity descriptions are given in appendix 1 at the end of this paper. The area shown in this figure was severely shaken and there were variable amounts of nonstructural content dislocation and damage (MMI VI). Areas with some nonstructural building damage, mostly damaged chimneys, are shown as intensity VII. The area with several collapsed and partially collapsed buildings, and fallen parapets and upper parts of walls is shown as intensity VIII.

Figure 8. Wells historical district showing partial collapse of buildings and facades; this was an area of intensity MMI VIII.

Figures 9 and 10. Two damaged chimneys at the same house from the earthquake. This is evidence of intensity MMI VII.

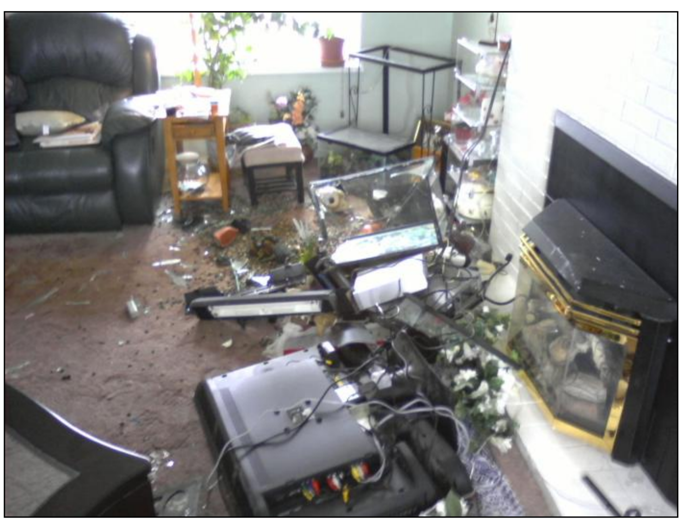

Figure 11. Content damage and dislocation that was typical of areas of intensity MMI VI (photo by resident).

Regional Intensity Map of the 2008 Wells Earthquake

The regional intensity map for the Wells earthquake (figure 12) was based on reviewed DYFI data set for Nevada and adjacent states. In some cases, newspaper inputs were reviewed and telephone inquiries to a community were made in an attempt to understand or verify DYFI intensity values or the single-value representations for communities. The regional intensity map was based on 216 locations with MMI values.

We postulate a small intensity MMI VI area for Town Creek Flat, the Snake Mountains, and the adjacent valley areas west of the Snake Mountains. Fairly extensive nonstructural content dislocation and damage was noted in these areas, but the sparse settlement of the region made defining the outside limits of this area nearly impossible. Within the intensity VI area are pockets of intensities VII and VIII, which are too small to show on the map. Most residents living within the MMI VI area were alarmed by the earthquake and had some picking up, re-shelving, and cleaning up to do.

In areas of intensity MMI V, people distinctly felt the earthquake, most were awakened by it, and several reacted to it, such as immediately going outside. A few shelf items and pictures toppled or fell. The earthquake shaking reportedly lasted for 10 to 30 seconds in intensity V locations. The intensity V area included all of northeastern Nevada north and east of Wells, and south of Wells for about 70 km. This area was strongly shaken.

In intensity MMI IV areas, most felt the shock, some began to react to the event, and a few were awakened. It was common for all in the house or building to have felt the earthquake. Some people who were outdoors also felt the event. Some shelves and lights rattled. Shaking was reported as mild to moderate and commonly lasted less than 20 seconds. The intensity IV area includes northeastern Nevada, south-central Idaho, and northwestern Utah. There were several intensity III locations scattered throughout the IV area.

Shaking was reported as lasting a few to 10 seconds in areas of MMI III. The reports were usually felt by the individual reporting and there were mixed results on whether others in the same building felt it. The motion was described as mild to moderate in nature and some shelves rattled slightly. The area of intensity III shaking includes central, northern, and eastern Nevada, easternmost Oregon, the southern half of Idaho, and the western part of Utah. There were a number of intensity II locations in the intensity III area, but they tended to be near the outer parts of the area.

In areas with intensity MMI II, generally only people in the upper stories of buildings felt or witnessed the earthquake shaking. Some slight back-and-forth motion was noted by some, whereas others observed the swaying of vertical window blinds and wind chimes, and the sloshing of water in a fish tank. We did not have enough data to fully evaluate the intensity II area, but it appears that this is a minimum intensity for all of Nevada and includes the central Great Valley in California. A USGS study indicates the intensity II area includes most of Utah, Idaho, southeasternmost Washington, southwesternmost Wyoming, and northwesternmost Arizona (Margaret Hopper, 2009, written communication). There were several intensity I locations within the intensity II area.

In areas of intensity MMI I, the earthquake was generally not felt; this area is largely undefined in this study, but it includes western California.

The sizes of the intensity zones determined using GIS software are presented in table 1. Approximate ranges in the radii of the intensity areas are also reported along with intensity outlier distances. The conservatively drawn isoseismal lines are inferred over large parts and thus, these values are approximate. Table 1 gives a rough idea of how large an area was shaken with a given intensity level. Possible uses of such information include creating earthquake scenarios where emergency personnel consider responding to the MMI VI and higher areas, which in the case of the Wells earthquake was about a 300 km^2 area, or an area with an approximate radius of 20 km around the epicenter.

Table 1. Areas, Radii, and Farthest Distances of Intensity Zones from the 2008 Wells Earthquake

Intensity zone	Area* (km^2)	Radius from epicenter (km)	Farthest intensity (km)
MMI VI	about 300	about 20	---
MMI V	11,955	75 – 100	120
MMI IV	15,744	125 – 220	300
MMI III	158,127	350 – 540	625

* areas measured with ArcGIS.

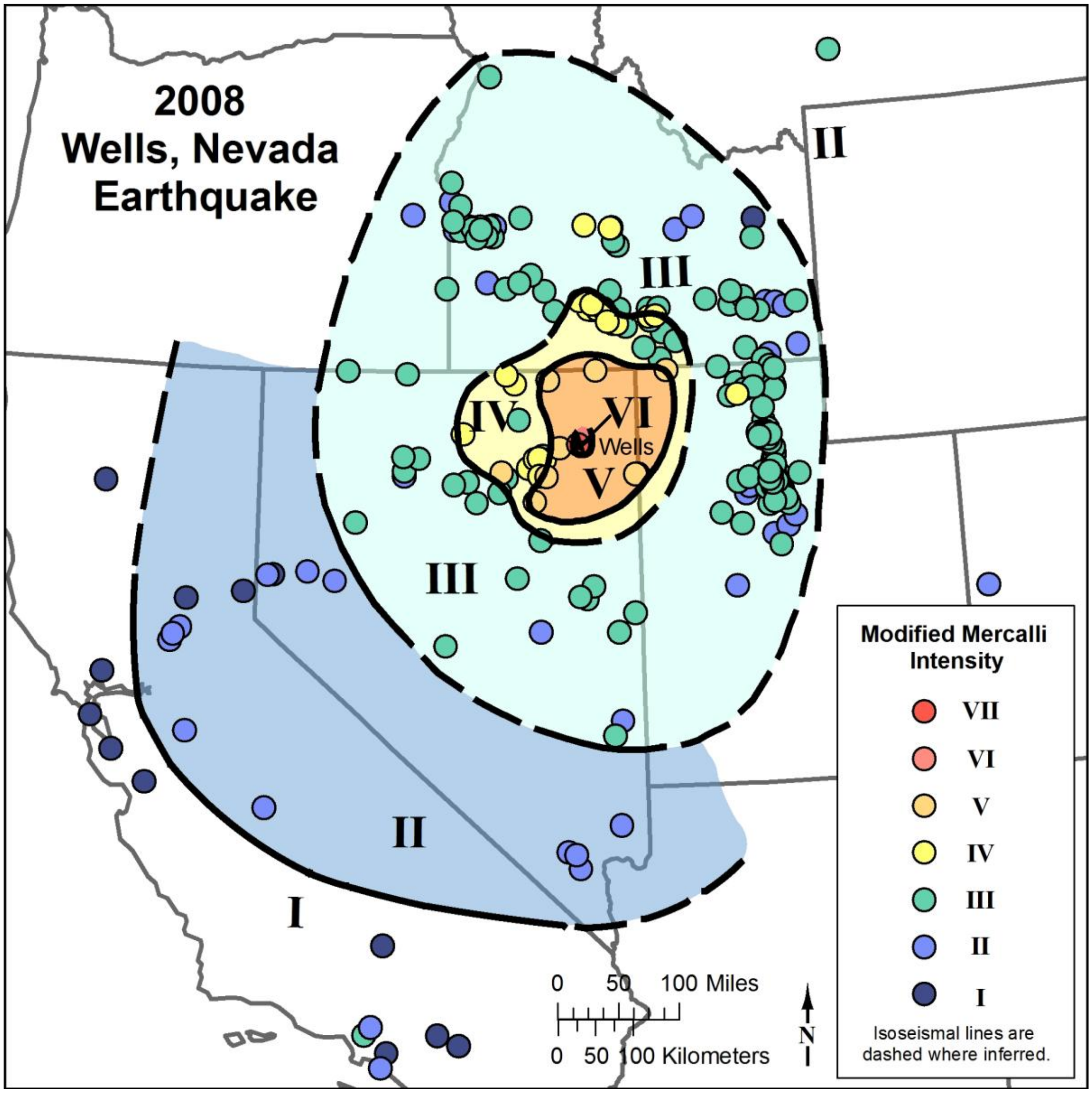

Figure 12. Regional 2008 Wells earthquake (M_W 6.0) Modified Mercalli Intensity map with isoseismal lines. Isoseismal lines are dashed where inferred.

Distributions of Intensity Values for Individual Communities

The regional and Wells intensity maps are based on single intensity values; however, the range in intensity values for communities was also informative. These ranges are reported in appendix 2 at the end of this paper. Some of the largest ranges in values are from locations within 100 km of the earthquake epicenter and likely reflect significant site effects. An example is Elko, Nevada, at a distance of about 80 km where reports range from MMI II to VI (figure 6). Elko has a wide range in topographic and geologic settings which are likely responsible for this range in intensities. For example, near Elko, rock-cored mountains are adjacent to partially saturated, young sediments in a basin; these different settings should have produced profoundly different levels of seismic shaking.

The larger ranges in intensities, spanning four to seven intensity values, were logically from communities that had many reports. Most Nevada communities were sparsely sampled and had only one or two intensity reports.

DISCUSSION AND RECOMMENDATIONS

Although the intensity data were adequate to define useful isoseismal areas, this effort was undertaken about a year after the earthquake – not optimum timing for creating detailed intensity maps. For future earthquakes, we recommend that detailed review of the DYFI data set be conducted within a few weeks after these entries are collected. Telephone calls, email inquiries, and/or site visits could then be undertaken for underrepresented and unrepresented communities to acquire additional infill detail for the intensity map. This study used a cut-off of a month post-event for the DYFI reports. Dewey and others (2002) found that imposing a 14-day cut-off period for the DYFI reports for the magnitude M_W 6.8 Nisqually, Washington earthquake had little effect on the overall intensity distribution. Figure 6 showed the rapid reporting of earthquakes within the first 24-hours that allows short time-period cut-offs to be used meaningfully. If proactive intensity data is needed, it should be obtained as rapidly as possible, because people's memory can have a perishable and modifiable effect on accuracy of intensity reports. Aftershocks can also complicate memories and damage.

Heavily damaged areas should be visited and geographically registered first-hand. Initial intensity maps of damaged areas should be drawn in the field, where they can be easily verified. Google Earth images work well for keeping track of damage if time and resources are limited.

After future large earthquakes, we recommend more detailed mapping of variations in intensity at locations with wide distributions of MMI values. Densely sampled intensity studies combined with local topography and geology might indicate areas of towns that could shake more strongly during future earthquakes. This could involve a linear or grid pattern of door-to-door surveys leaving postage-paid questionnaires for people who are not home or who are more comfortable with that mode of response. This would likely lead to some valuable insights into potential seismic hazard microzonation of a community, that could be verified by more rigorous techniques, such as seismic velocity measurements. Strong earthquakes offer unique opportunities to see variations in shaking effects in communities.

Our method of drawing isoseismal lines for the Wells earthquake has resulted in smoother contours than most other intensity maps from historical earthquakes in Nevada. This is partly due to a lack of more detailed data which might have otherwise indicated some more noticeable differences between shaking in valleys versus the ranges, and so forth. These smoother contours may also result from the approach of using the largest most-common value to represent the intensity of a community. A casual comparison of the Wells earthquake intensity map with other, similar magnitude regional historical earthquake intensity maps showed that overall, the isoseismal areas were of comparable sizes.

The regional MMI map offers several advantages over the CIIM map. The first advantage is that the intensity data used are the result of a review of the DYFI data combined into single representative values for a community, and augmented with other data, including first-hand observations, making it a more complete data set. A second advantage is the more complete view of the intensity areas in the MMI map versus the CIIM maps, even though several boundaries are inferred and in most areas there were no reports. This helps people mentally fill in between the data when thinking about the Wells earthquake and gain a more complete picture. Activities such as creating earthquake scenarios for emergency planning require participants to visualize earthquake shaking more like that represented on the MMI maps, and the Wells earthquake is one of the most recent examples that can be used. A third advantage is that the decrease in intensity, or shaking, with distance can be more easily seen than in the CIIM portrayals, as well as where the local intensity exceptions are. A fourth advantage is that the MMI maps facilitate the calculation of intensity parameters, such as isoseismal areas, which can also be used in earthquake scenarios. These advantages of the MMI maps are laid out for clarity, but the two types of intensity maps actually complement each other nicely and there are definite advantages of the CIIM maps. A local intensity map of the areas of strongest shaking is difficult to make with the DYFI data because many people in these areas did not fill out the Internet questionnaire, but the regional map was greatly facilitated by the DYFI data. Both types of maps are useful.

The CIIM maps for the Wells earthquake are good portrayals of the intensity as compared to our MMI maps. The CIIM maps clearly show the magnitude and extent of shaking intensity in the region, and the geocoded version has the ability to rapidly verify the locations of the strongest shaking. The major advantage of the CIIM maps is the speed with which people's experiences can be translated into a map that can be used by emergency responders, scientists, and the public; this can happen as fast as people can enter their experiences. To this end, the CIIM maps worked well for the Wells earthquake, and compare favorably with our MMI maps.

CONCLUSIONS

Many people in central, northern, and eastern Nevada distinctly felt the 2008 Wells earthquake, and northeastern Nevada was shaken fairly strongly by it. These shaking effects were successfully captured and characterized by the creation of MMI maps for Wells and the Nevada region. We constructed the maps using the USGS DYFI data and first-hand observations for the damaged areas in Wells. The individual DYFI reports were reviewed, assigned intensity values, and combined for communities to get a single, largest most-common intensity value. For the local MMI map of Wells, first-hand observations were used. These MMI maps show the decrease in intensity, or shaking, with distance and give a good visual representation of the extent of the effects from the Wells earthquake.

Damaging intensities of MMI VII occurred over about half of the town of Wells, and MMI VIII occurred in the historical district where older buildings collapsed and partially collapsed. In Town Creek Flat and adjacent areas, intensities VI and VII occurred. Overall, potentially damaging intensities (MMI VI) occurred over an area of roughly 300 km^2 around the earthquake area. The MMI V region, where the earthquake was strongly felt, was an approximately 12,000 km^2 area of northeastern Nevada and northwestern Utah. The MMI map shows that over half of Nevada distinctly felt the Wells earthquake (≥MMI III).

Intensity distributions for most communities were small because of very small reporting numbers, but in a few communities that had many reports, intensity distributions were up to seven intensity values wide. Seismic hazard microzonation should be considered for those communities to identify areas that might shake more violently during future earthquakes.

The MMI maps offer a more complete picture of the earthquake effects, one that is more intuitively correct, than the CIIM map. On the other hand, the CIIM maps are verified by this more detailed study and appear to be credible representations of intensity provided in a rapid manner. A caution to users of the DYFI data set is that people in the area of damaging levels of shaking and in more rural settings did not participate in the DYFI questionnaire, partly because people were more focused on the damage and dealing with the earthquake and partly because Internet was not available everywhere.

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APPENDICES

Appendix 1. Modified Mercalli Intensity Levels and Descriptions

Intensity I. Not Felt

Not felt except by a few people under especially favorable circumstances.

Intensity II. Scarcely Felt

Felt only by a few people at rest, especially in the upper floors of buildings.

Intensity III. Weak Shaking

Felt quite noticeably indoors, especially on the upper floors of buildings, but many people do not recognize it as an earthquake. Hanging objects swing.

Intensity IV. Moderate, Widely Observed Shaking

During the day, felt indoors by many, outdoors by few. At night some awakened, especially light sleepers. Dishes, windows, doors disturbed; walls make creaking sound.

Intensity V. Strong Shaking

Felt by nearly everybody indoors, felt by many outdoors, awakened many if not most. Frightened a few. Some dishes and windows broken. Overturned vases or small unstable objects.

Intensity VI. Slightly Damaging Shaking

Felt by all, many frightened and run outdoors. Some alarm among individuals. Awakened all. People move about unsteadily during the event. Damage slight in poorly built buildings, small amounts of fallen plaster, cracked plaster, broken dishes and glassware in considerable quantities, also some broken windows, fall of knickknacks, books, pictures, some heavy furniture moved and overturned.

Intensity VII. Moderately Damaging Shaking

Frightened all, general alarm, all run outdoors, some or many find it difficult to stand. Waves in ponds, lakes, running water, water turbid from being stirred up. Suspended objects made to quiver. Some rock falls. Damage considerable in poorly built or weak buildings, adobe houses, unreinforced masonry buildings, old walls, and spires. Chimneys cracked to a considerable extent. Fall of plaster in large amounts. Numerous windows broken. Loosened brickwork and tiles shaken down. Fall of cornices; bricks and stones dislodged. Damage considerable to concrete irrigation ditches.

Intensity VIII. Heavily Damaging Shaking

General fright, alarm approaches panic. Trees shaken strongly, branches and trunks broken off. Liquefaction occurs locally accompanied by ejected sand or mud in small amounts. Changes in levels and temperatures of springs.

Many rock falls and landslides. Damage slight in well-built structures designed with earthquake resistance, considerable in ordinary substantial buildings, weak structures partially collapsed, racked, and tumbled down. Fall of walls. Seriously cracked and broken stone walls. Twisting, fall of chimneys, columns, monuments, factory stacks, and towers. Very heavy furniture moved conspicuously or overturned.

Intensity IX. Destructive Shaking

General panic. Conspicuous cracked ground. Damage considerable in specially designed structures, great in substantial masonry buildings with some collapse. Buildings wholly shifted off foundations. Well designed frame structures thrown out of plumb and racked. Reservoirs damaged and underground pipes sometimes broken.

Intensity X. Very Destructive Shaking and Ground Displacement

Cracked ground, especially when loose and wet. Fissures parallel along canal and stream banks. Landslides considerable from river banks and steep cliffs. Changed levels in many water wells. Water thrown on banks of canals, lakes, and rivers. Some well-built structures destroyed. Most masonry buildings destroyed along with their foundations. Rails bent slightly. Serious damage to dams, dikes, and embankments.

Intensity XI. Devastating Shaking and Ground Displacement

Widespread ground disturbance, broad fissures, earth slumps, and land slips in soft, wet, ground. Ejection of large amounts of water charged with sand and mud. Few, if any masonry structures remain standing. Severe damage to wood-framed structures. Great damage to dams, dikes, and embankments. Bridges destroyed by wracking of support piers or pillars. Rails bent greatly. Underground pipelines completely out of service.

Intensity XII. Complete Devastation from Shaking and Ground Displacement

Damage total. Waves seen on ground surface. Objects thrown up in the air. Ground greatly disturbed. Waterways blocked by landslides. Large rock masses wrenched loose. Fault displacement of surface with notable horizontal and vertical displacements.

Appendix 2. Number of Reported Intensities for Each Site in Nevada and Final Map Values Used

TOWN	I	II	III	IV	V	VI	VII	Map
Argenta			1					III
Baker			1					III
Battle Mountain		3	26	1	1	1		III
Caliente			1					III
Carlin / Gold Quarry Mine				1	1			V
Carlin		2	9	3				III
Crescent Valley			1					III
Deeth					3			V
Denio			1					III
Devils Gate			1					III
Elburz				1	1			V
Elko		7	45	53	13	1		IV
Ely / Bald Mountain Mine			1					III
Ely	1	3	8	2				III
Eureka				5				III
Fallon		3	1					II
Fernley	1	1						II
Golconda			2					III
Henderson	1	1						II
Jackpot		2	1	5	3			V
Jarbidge					1			V
Jerritt Canyon (mill site)			1					III
Jiggs				1	1			V
Lamoille			1		1			V
Las Vegas		1	1					II
Lovelock		1	4					III
McDermitt	1		1					III
McGill		1	4					III
Midas				1				IV
Mountain City				1				IV
North Las Vegas		1						II
Osino				1				IV
Overton		1						II
Owyhee		1	1	1				IV
Palisade			1					III
Panaca		1						II
Railroad Valley		1						II
Reno	4	3						II
Round Mountain			1					III
Ruth			1					III
Ryndon			1	2				IV
Shoshone			1					III
Sparks	1							I
Spring Creek		10	36	36	10	1	1	IV
Wells			2	1	2	7	9	VIII
West Wendover			4	7	4	1		V
Winnemucca		6	5	2				III
Winnemucca, 13 miles south of			1					III
Winnemucca, 20 miles south of		1						II

TOWN	I	II	III	IV	V	VI	VII	Map
Argenta			1					III
Baker		1						III
Battle Mountain		3	26	1	1	1		III
Caliente			1					III
Carlin/Gold Quarry Mine			1	1				V
Carlin		2	9	3				III
Crescent Valley			1					III
Deeth					3			V
Denio			1					III
Devils Gate			1					III
Elburz				1	1			V
Elko		7	45	53	13	1		IV
Ely/Bald Mountain Mine			1					III
Ely	1	3	8	2				III
Eureka				5				III
Fallon		3	1					II
Fernley	1	1						II
Golconda			2					III
Henderson	1	1						II
Jackpot		2	1	5	3			V
Jarbidge					1			V
Jerritt Canyon (mill site)			1					III
Jiggs				1	1			V
Lamoille			1		1			V
Las Vegas		1	1					II
Lovelock		1	4					III
McDermitt	1		1					III
McGill		1	4					III
Midas				1				IV
Mountain City				1				IV
North Las Vegas		1						II
Osino				1				IV
Overton		1						II
Owyhee		1	1	1				IV
Palisade			1					III
Panaca		1						II
Railroad Valley		1						II
Reno	4	3						II
Round Mountain			1					III
Ruth			1					III
Ryndon			1	2				IV
Shoshone			1					III
Sparks	1							I
Spring Creek		10	36	36	10	1	1	IV
Wells			2	1	2	7	9	VIII
West Wendover			4	7	4	1		V
Winnemucca		6	5	2				III
Winnemucca, 13 miles south of			1					III
Winnemucca, 20 miles south of		1						II