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SCIENCE AND PUBLIC POLICY OF EARTHQUAKE HAZARD MITIGATION IN THE NEW MADRID SEISMIC ZONE

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SCIENCE AND PUBLIC POLICY OF EARTHQUAKE HAZARD MITIGATION IN THE NEW MADRID SEISMIC ZONE

THESIS

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in the College of Arts and Sciences at the University of Kentucky

By

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ABSTRACT OF THESIS

SCIENCE AND PUBLIC POLICY
OF EARTHQUAKE HAZARD MITIGATION
IN THE NEW MADRID SEISMIC ZONE

In the central United States, undefined earthquake sources, long earthquake recurrence intervals and uncertain ground motion attenuation models have contributed to an overstatement of regional seismic hazard for the New Madrid Seismic Zone on the National Seismic Hazard Maps. This study examined concerns regarding scientific uncertainties, overly stringent seismic mitigation policies and depressed local economy in western Kentucky through a series of informal interviews with local businessmen, public officials, and other professionals in occupations associated with seismic mitigation. Scientific and relative economic analyses were then performed using scenario earthquake models developed with FEMA's Hazus-MH software. Effects of the 2008 Wenchuan earthquake in central China and seismic mitigation policies in use there were considered for potential parallels and learning opportunities. Finally, suggestions for continued scientific research, additional educational opportunities for laymen and engineering professionals, and changes in the application of current earthquake science to public policy in the central United States were outlined with the goal of easing western Kentucky economic issues while maintaining acceptable public safety conditions.

KEYWORDS: New Madrid Seismic Zone, Seismicity, Earthquake Hazard Mitigation, Economic Analysis, Public Policy

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April 22, 2014

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April 22, 2014

For Kay and Ray, Madeleine and Dennis,
Scott, Brett and Hailey
who are my best teachers

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Last to be mentioned but first always in my thoughts, thank you to my family for their support. It's a big family and it would take more room than I have here to name all of them, but any success I enjoy is due to a group effort by my husband, children, grandchildren, parents, siblings, in-laws, nieces, and nephews. Best family ever!

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CHAPTER 1: INTRODUCTION

1.1 Background

The New Madrid Seismic Zone (NMSZ) is a well-documented region of historic and pre-historic seismicity underlying the upper Mississippi Embayment in a southwest-northeast direction across the central United States (Figure 1.1). Sensational eye-witness accounts of the Mississippi River flowing backward (Johnston and Schweig, 1996), coal and sand thrown out of the earth, house chimneys toppled, and hills and islands sunken into rivers or swamps (Nuttli, 1973) attest to the violence of the last great earthquake sequence along this fault zone in the winter of 1811-1812. However, the NMSZ also has long quiet periods characterized by minor seismic activity as illustrated by the small number of earthquakes greater than magnitude 5.0 since the aftershocks to the 1811-1812 earthquake sequence died down 200 years ago. In fact, an online U.S. Geological Survey (USGS) Earthquake Catalog query for events greater than magnitude 5.0 anywhere in the U.S. east of the Rocky Mountains returns only 10 events since 1973, only 2 of which are even remotely close to the NMSZ (USGS, 2014a).

Because earthquakes of magnitudes greater than 5.0 are much less common in this intraplate region than they are along tectonic plate boundaries, more behavioral patterns must be inferred from fewer data than in regions where data are ample (Stein and Wysession, 2003). Rather than relying on documented ground motions and objectively recorded data as we would like to do, scientists and local residents alike are left to interpret a very few subjective accounts of historical events, and when possible piece together pre-historic events from paleoseismic studies of sand blows and other structural and stratigraphic evidence (Johnston and Schweig, 1996; Van Arsdale et al., 1998; Tuttle et al., 2002; Tuttle et al., 2005; etc.). Furthermore, despite widespread research into area seismicity, the causal mechanism of the NMSZ has yet to be identified (Grollimund and Zoback, 2001; Pollitz et al., 2001; Calais et al., 2010). These circumstances make it difficult to assess the regional seismic hazard with a high degree of confidence.

As is often the case with necessarily incomplete science, mathematical models have been created to attempt to explain and recreate seismicity patterns for many earthquake-prone areas around the world, including the New Madrid region. But models are by definition an uncertain substitute for adequate real data. They are representative only in the limited circumstances where the variables they consider are adequately represented and no other factors are present. The number of seismic attenuation models alone (Frankel et al., 1996; Toro et al., 1997; Somerville et al., 2001; Silva et al., 2002; Campbell, 2003; Tavakoli and Pezeshk, 2005; Atkinson and Boore, 2006; and others) and publications detailing the differences between them should alert any thoughtful reader to the potential pitfalls of adopting any one model over another. Many earthquake hazard and risk models are based on data from the San Andreas Fault Complex and other western U.S. seismic zones for which many data have been collected (Cornell, 1968; Bazzurro and Cornell, 1999; Campbell, 2003), but a combination of differences in ground motion attenuation rates due to soil and bedrock conditions and differences in recurrence intervals of major seismic events makes west coast data less applicable for central U.S. probability analyses.

In the United States, many decisions about earthquake hazard mitigation are based on the National Seismic Hazard Map (NSHM) series produced by the U.S. Geological Survey (USGS) as part of the National Earthquake Hazard Reduction Program (NEHRP). Documentation included with the maps states that they "display earthquake ground motions for various probability levels across the United States and are applied in seismic provisions of building codes, insurance rate structures, risk assessments, and other public policy… The resulting maps… describe the frequency of exceeding a set of ground motions" (Petersen et al., 2008). However, there are problems associated with the maps and the resulting engineering design criteria and regulations which deserve further attention. In fact, the 2008 NSHM series indicate that the NMSZ has a higher ground motion hazard than either San Francisco or Los Angeles, California (Figures 1.2 and 1.3), both areas located along the San Andreas and associated fault systems (Petersen et al., 2008). The higher hazard assigned to the NMSZ seems unlikely when the San Andreas experiences much more frequent earthquakes than the New Madrid region.

The NSHM series are produced using a probabilistic seismic hazard analysis (PSHA) first published in the late 1960s as a mathematical model of the range of potential ground motion values for a given site. The analysis was developed in order to assess seismic risk of individual sites for engineering purposes (Cornell, 1968). PSHA methodology involves using established statistical models of earthquake occurrence and ground-motion attenuation to calculate the annual probability of exceedance of a specified ground motion level at a given site. However, PSHA methods are not viable without sufficient observations (data) for meaningful statistical and probability analysis. The acknowledged lack of data for the central U.S. (Petersen et al., 2008) requires more speculative calculations when applying PSHA in the central U.S. than for the western U.S. where data are numerous. Flaws in the underlying PSHA assumptions of equal likelihood of earthquake occurrence within a region, constant average occurrence rate, Poisson (memory-less) earthquake occurrence, and extrapolation of a dimensionless unit (annual probability of exceedance) into a time-dependent unit (return period) also allow for miscalculation and misinterpretation of model results (Wang, 2007; Wang, 2011). Compounded uncertainty, the overstatement of uncertainty created by calculating a response from multiple uncertain variables, is a common result of working with models and applies to the use of PSHA methods. Additionally, the requirement for weighting the significance of variables within PSHA calculations allows for bias through personal opinion of the particular scientists or engineers conducting the probabilistic analysis (Klugel, 2011). All of these complications with either PSHA or modeling in general contribute to a lack of confidence in the resulting NSHM for the central United States. Either overstatement or understatement of hazard is possible depending on the particular site location in relation to the maps, but sites within or near the NMSZ are likely to have an overstated seismic hazard due to the significance attributed to historic area seismicity during the weighting of hazards in the map creation process.

The NSHM series, with their possibly overstated hazard assessment for the NMSZ, are then used to develop engineering standards (for example, the American Society of Civil Engineers' ASCE/SEI 7-10, Minimum Design Loads for Buildings and Other Structures; and the American Association of State Highway and Transportation Officials' (AASHTO) Policy on Geometric Design of Highways and Streets); building codes (including the International Code Council's International Building Code, the Commonwealth of Kentucky's Kentucky Building Code, and others); insurance rates; risk assessments; emergency management plans; and other public policies. On the USGS Earthquake Hazards Program's website for Seismic Design Maps & Tools (USGS, 2014b), design maps can be generated for a specific site using any of four different building code reference documents: the International Building Code (IBC), the

ASCE/SEI 7 standard, the NEHRP Recommended Seismic Provisions, or the AASHTO Guide Specifications for LRFD Seismic Bridge Design. It is the responsibility of each independent engineering organization to determine how to apply the information contained in the NSHM series, but as the acknowledged seismic authority in the United States the maps are universally accepted as the best current science. The building and engineering codes are then in turn adopted by individual states as they see fit, but again with the general acceptance as authorities on engineering and construction best practices. And so as each expert organization relies on the other, the original science gets passed on to the public through codification in local public policies. In this manner, the Commonwealth of Kentucky has adopted the IBC with few reservations and exceptions as its accepted building code. At each step in this process, any uncertainties in the underlying calculations are accepted, compounded and codified as mitigation requirements.

Government officials, economic development agencies and business people in the Jackson Purchase region of western Kentucky have raised the issue of overly stringent seismic mitigation policies adversely affecting economic development within the region by discouraging new businesses from locating in the area (City of Paducah, 2012; PACOC, 2012; L. Hayes, personal communication, 2013; S. Doolittle, personal communication, 2013; C. Chancellor, personal communication, 2013). Wang and Cobb (2012) found that application of NEHRP provisions to public policy within the NMSZ has resulted in unrealistic building code expectations and, in some areas, a disincentive for construction. For example, based on NEHRP recommendations resulting from the 2008 NSHM series, the Paducah Gaseous Diffusion Plant, a federal facility, would be required to incorporate seismic design to 0.8 g for a new landfill (Wang and Cobb, 2012). Additionally, residential construction in western Kentucky would require the services of a design professional under the terms of the International Residential Code of 2000 (SEAOK, 2002). In many cases, such provisions make construction too costly. One of the most frequently asked questions is why building codes are calibrated for a 2500-year earthquake return event when current science tells us to prepare for a 500-year event, and even that is 10 times longer than the expected useful lifetime for new building construction. For comparison, flood building codes are set for a 100-year return event (1% probability in 1 year) (ICC, 2000). There appears to be a chain effect from the beginning seismic assumptions and PSHA methodology for the NMSZ, through the applications for design maps and building codes, to the end result of suppressed economic growth rather than a safer society.

1.2 Project Objectives

In an effort to address the concerns of citizens, businessmen and government officials regarding current seismic hazard mitigation policies in western Kentucky, this study used a range of historical parameters and alternative modeling methods to create scenario seismic hazard maps for comparison to the NSHM series. Relative economic and engineering analyses were performed using the revised models and a federal hazard and economic analysis software package, Hazus-MH (FEMA, 2012a). Comparisons were also made to seismic hazard mitigation policies in the area affected by the 2008 Wenchuan, China, earthquake (magnitude 7.9; 12 May 2008, eastern Sichuan Province, China) since the China region has a much longer recorded history of earthquake effects as well as a shorter recurrence interval, and the Chinese national government is actively involved in earthquake research and seismic hazard mitigation. Lessons learned from the 2008 Wenchuan event were used to recommend more informed policy decisions in the NMSZ. Finally, several recommendations were developed with the intention of reducing impacts to western Kentucky economy while still maintaining reasonable safety standards. The following is a list of tasks undertaken to complete the objectives:

Task 1. Collected existing ground motion data and estimates of ground motion for historic seismic events in the NMSZ.

Task 2. Identified knowledge of current science and engineering practices and concerns regarding public policies and economic impacts related to seismic hazard mitigation with local (Paducah city and McCracken County, Kentucky), state (Kentucky) and federal agencies, businessmen and individuals.

Task 3. Collected literature regarding Chinese engineering and seismic hazard mitigation policies in the area affected by the 12 May 2008 Wenchuan, China, earthquake.

Task 4. Developed a series of alternate seismic hazard scenarios for the NMSZ based on historical event estimates.

Task 5. Performed economic analyses for the seismic hazard scenarios using FEMA Hazus software options.

Task 6. Compared seismic hazard mitigation policies in the 2008 Wenchuan, China, earthquake-affected area to current mitigation policies in western Kentucky.

Task 7. Used the alternative seismic hazard maps and economic analyses, and Chinese mitigation policies to develop recommendations for research, education and public policy actions for western Kentucky.

Task 8. Prepared thesis and data for dissemination.

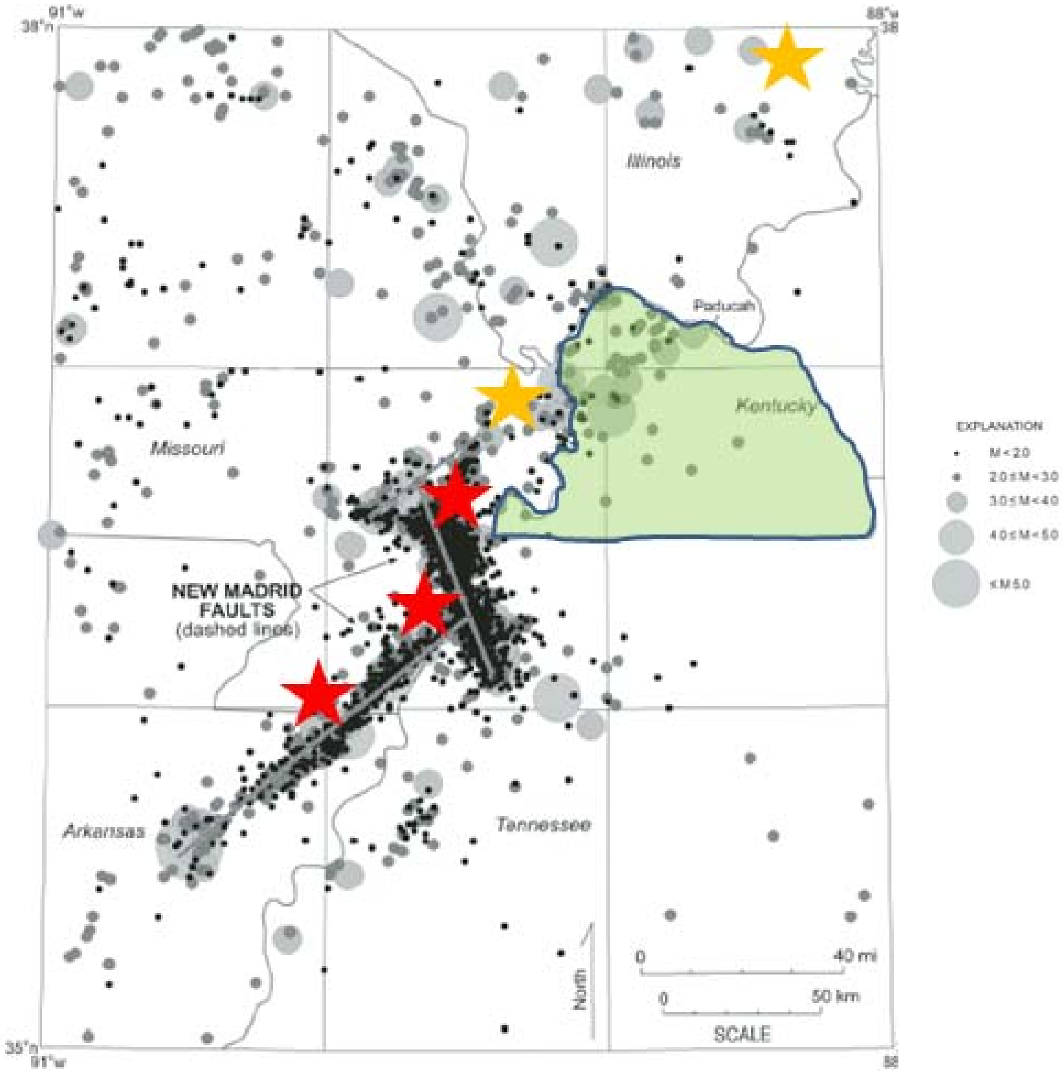


Figure 1.1: The New Madrid Seismic Zone. The New Madrid Seismic Zone of the central United States is illustrated by seismic activity between 1974 and 2004. Red stars indicate approximate locations of the three main 1811-1812 earthquakes on (from southwest to northeast) 16 December 1811 (~M7.7), 23 January 1812 (~M7.5), and 7 February 1812 (~M7.7). Yellow stars indicate locations of large earthquakes since then: near Charleston, MO (1895, M6.6), and in southern Illinois (1968, M5.4). The green highlighted area is the Jackson Purchase region in western Kentucky. (Modified from Wang, 2007.)

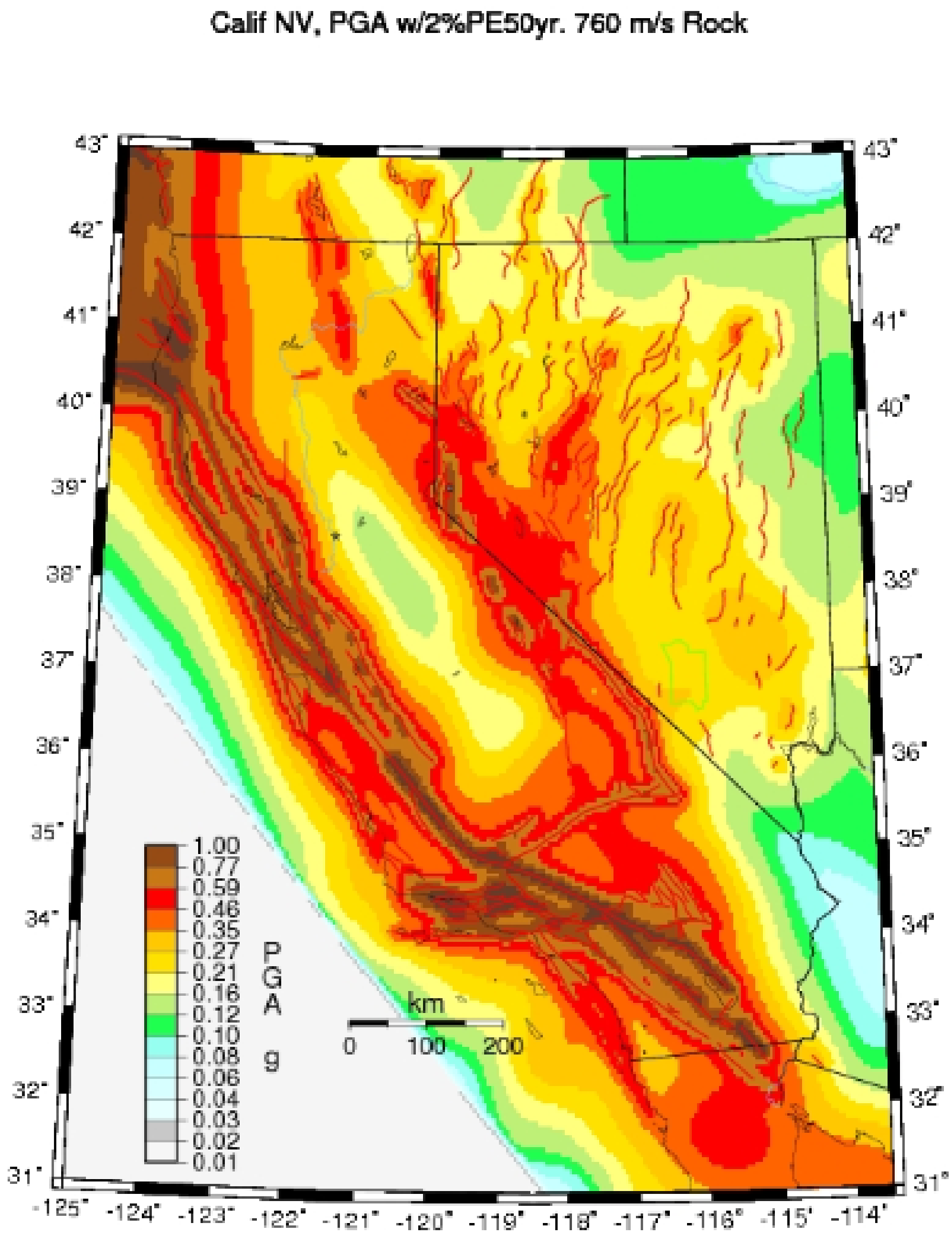


Figure 1.2: Peak Ground Acceleration, Western U.S. The 2008 National Seismic Hazard Map showing peak ground acceleration (g) in California and Nevada with 2% in 50 years probability of exceedance, with a high value of 1.0 g. (From USGS, 2012a.)

PGA with 2%/50 yr PE, 2008

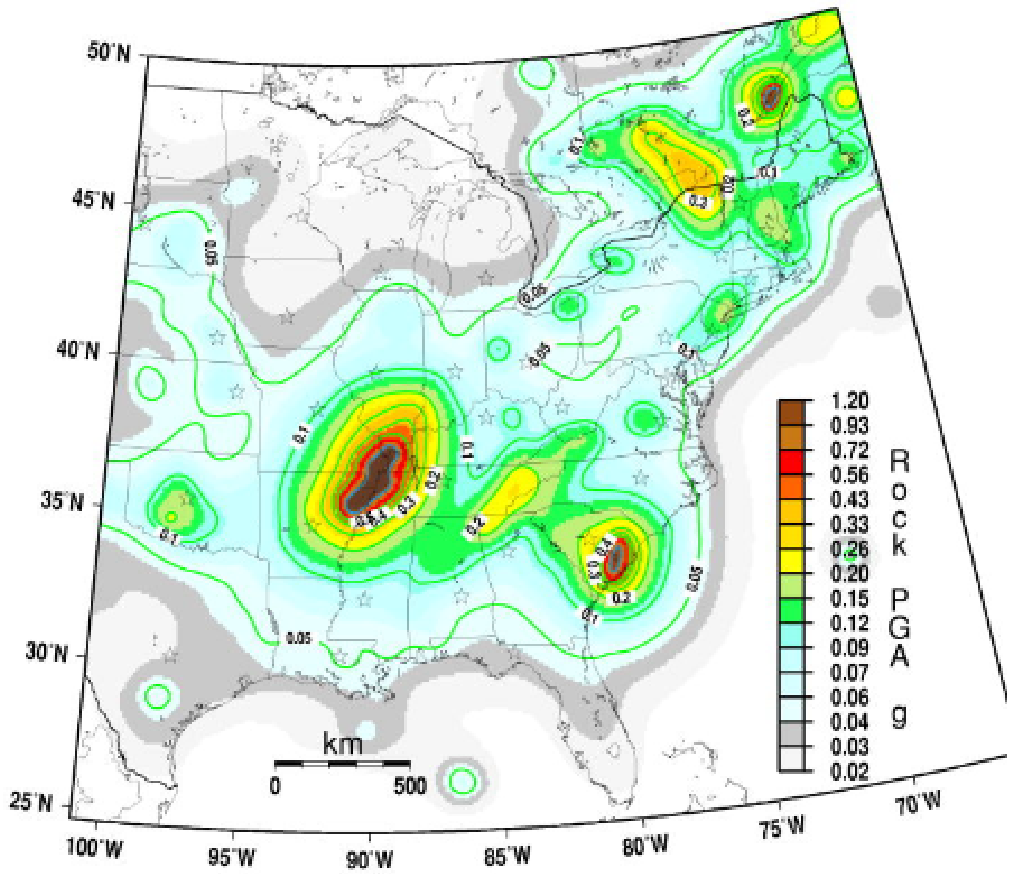


Figure 1.3: Peak Ground Acceleration, Central and Eastern U.S. The 2008 National Seismic Hazard Map showing peak ground acceleration (g) in the central and eastern United States with 2% in 50 years probability of exceedance. Data for the map indicate a high value of greater than 1.2 g in the New Madrid Seismic Zone. (From USGS, 2012a.)

CHAPTER 2: GEOLOGIC SETTING

2.1 New Madrid Seismic Zone, Historic Earthquakes

The New Madrid Seismic Zone (NMSZ) is an intraplate fault zone within the North American tectonic plate. One of several seismic zones within the central and eastern United States which affect Kentucky (see Figure 2.1), the New Madrid was named for a series of earthquakes that occurred between December 1811 and February 1812, in the last of which the town of New Madrid, Missouri was destroyed (Figure 2.2). There were at least three great earthquakes in the 1811-1812 cluster (12/16/1811, 01/23/1812, and 02/07/1812). Although no seismographic records were available at that time, estimates of the magnitudes and intensities of those earthquakes have been made using eye-witness accounts of the events, and journals and logs of scientists who kept records of effects in their geographic areas. Each of the events has been estimated to be between magnitude 6.7 and 8.1, but no general consensus has been reached to narrow this range. Over the two month period, the largest events occurred chronologically from south to north along the northeastward trend that the seismic zone exhibits (Figure 1.1).

Shaking attributed to these earthquakes was reported from New Orleans, Louisiana, at the gulf coast to the south, to the Atlantic Coast states to the east, up into New Hampshire to the northeast, and to Toronto, Canada, to the north (Nuttli, 1973). Few reports came from farther west since at the time there were few settlements in that direction. Widespread effects of this series of earthquakes and their aftershocks included opening of ground chasms and rifts; changes of ground elevation, both uplifting and subsiding across the region; sand blows and discharge of other earth materials; soil liquefaction; sulfurous smells; and unusual lights and sounds (Nuttli, 1973). The Reelfoot Lake in northwestern Tennessee, for example, was formed when subsidence on the eastern side of the Reelfoot Fault dammed a small stream causing a broad but shallow body of water to form. Over 200 years later, trees that began life in a field continue to grow with their trunks submerged in the lake (Figure 2.3). It is generally agreed that the only reason there was not more damage to the built environment was that the region was only sparsely populated at the time and structures in the near area were low to the ground and of simple construction. The largest earthquakes since 1812 have been a magnitude 6.6 in 1895 and 5.4 in 1968, both of which continued the northeasterly directional trend (Figure 1.1).

2.2 New Madrid Seismic Zone, General Geology

Lacking seismographic data from large earthquakes, research on the subsurface structure of the area has been pursued (Zoback et al., 1980; Johnston and Schweig, 1996; Street et al., 1997a; Street et al., 1997b; Woolery and Street, 2002; McBride et al., 2003; Wang and Woolery, 2006; Csontos and Van Arsdale, 2008; and others). Studies have shown that there is a large seismically active fault system underlying the upper Mississippi Embayment, believed to be a reactivated failed rift zone. The zone extends 240 km in a southwest/northeast orientation from northeastern Arkansas into southeastern Missouri, touching the western boundaries of Tennessee and Kentucky, and exhibits shallow seismicity in the upper 25 km depth. It consists of three main fault sections: the southwestern and northeastern sections are right-lateral faults slightly offset from one another but generally striking northeast, following the southwest-northeast trend of the Mississippi Embayment, while a central step-over thrust fault section extends southeast-northwest between them, connecting the offset. Sediments in this area of the Mississippi Embayment range from 0 to 1.1 km (3600 feet) deep.

Part of the uncertainty for earthquake modeling in the region is the inability to confirm great earthquake recurrence intervals. We have only 200 years of historic data, some of which is eye-witness accounts and possibly exaggerated. Paleoseismic data from investigation of sand blows and soil horizon shifts (Tuttle et al., 2002; Holbrook et al., 2006) indicate pre-historic earthquake dates of 1400 and 900 AD, and models from modern data (Hough and Page, 2011) indicate recurrence intervals in the range of 500 to 1000 years. The longer 1000-year estimate is supported by GIS data (Newman et al., 1999; Calais and Stein, 2009; and Stein, 2010) showing little or no continuing deformation in the area.

Although much research has been conducted in the area, the seismic mechanism is still unknown. Theories include isostatic rebound from the last North American glaciation (Grollimund and Zoback, 2001), a sinking mafic body deforming the underlying crust (Pollitz et al., 2001), and extensive riverine erosion in the Mississippi River Valley allowing for crustal rebound (Calais et al., 2010).

2.3 Wenchuan, China, General Geology and Earthquake History

China has experienced many earthquake disasters throughout its extensive history. The 1556 Shansi earthquake resulted in about 830,000 fatalities, the highest number of recorded fatalities for any earthquake event. The 2008 Wenchuan, China, earthquake resulted in approximately 90,000 fatalities and more than $110 billion in damages (Xie et al., 2009). In response to its known earthquake hazards, China has formulated policies for earthquake hazard mitigation (discussed in Section 4.3). Mitigation policies in the area affected by the 2008 Wenchuan, China, earthquake have been analyzed and compared to current NMSZ earthquake mitigation policies (Section 5.3). Therefore, some background for the Wenchuan, China region geology will be pertinent to understanding.

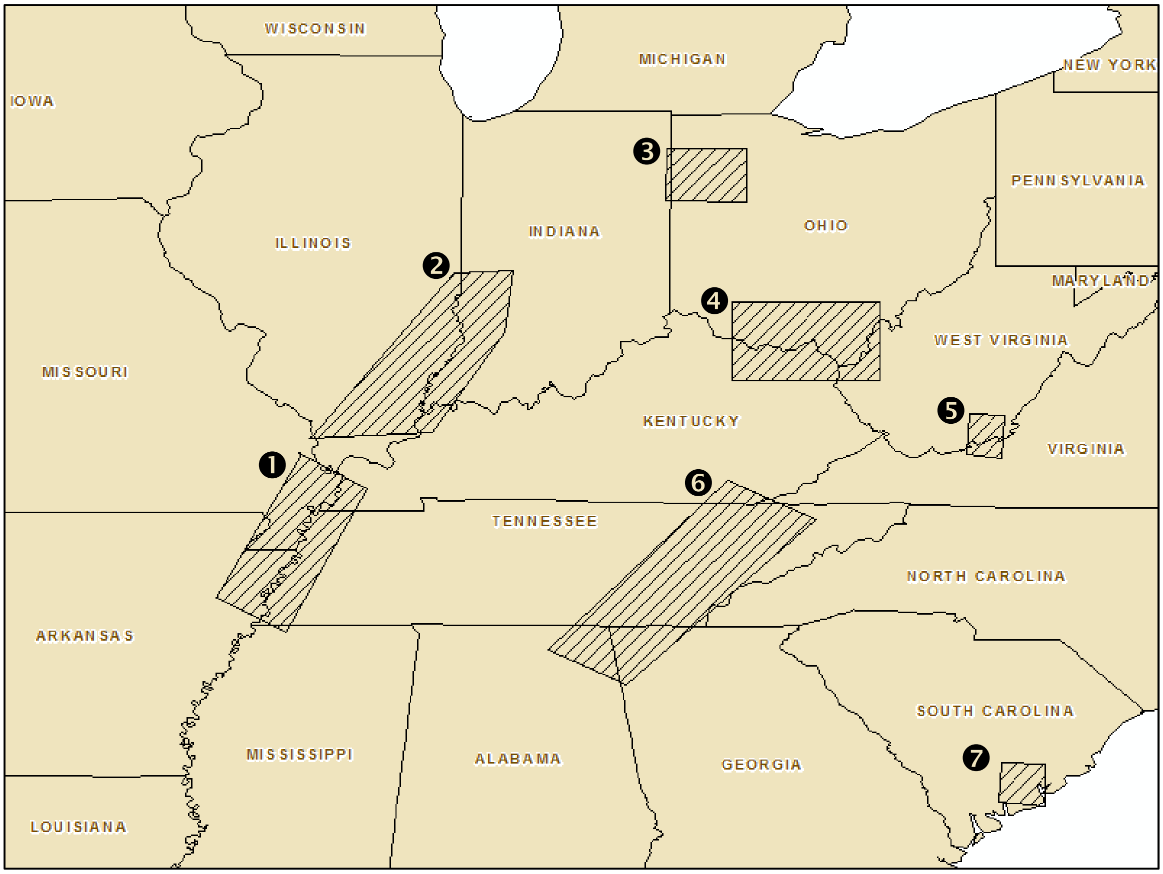
Although the People's Republic of China is located entirely upon the Eurasia tectonic plate, it is greatly affected by interactions between the Austral-Indian plate to the west and south and the Yangtze Plate, a subplate of the Eurasia plate that comprises most of the south of China (USGS, 2008c). As the India tectonic plate to the southwest pushes northward against the Tibetan Plateau, the Tibetan Plateau spreads laterally, pushing eastward against the Yangtze Plate (Figure 2.4). The Longmen Shan Fault is the suture between the uplifted Tibetan Plateau and the neighboring strong Yangtze Plate. Movement on the northeast-striking Longmen Shan Fault or a related thrust fault along the northwestern edge of the Sichuan basin is the reported source for the magnitude 7.9 earthquake of 12 May 2008 (Burchfiel et al., 2008) (Figure 2.5). The event is often referred to as either the Eastern Sichuan earthquake, after the province, or the Wenchuan earthquake, after the county in which the epicenter occurred. The epicenter was located only 80 km from Chengdu, the provincial capital of Sichuan. The focal point was estimated at a depth of 19 km (USGS, 2008a) and a rupture length of approximately 300 km was observed in two sections (Xu et al., 2009).

Effects from the 2008 Wenchuan earthquake included widespread shaking with a maximum intensity of IX in the near (Wenchuan) area; landslides along the Tibetan Plateau front; ground surface faulting and fracturing; ground subsidence; and seiches as far away as Bangladesh (USGS, 2008b). Shaking was felt as far away as the Thailand coast to the south, to the eastern continental coast and Taiwan to the east, and in Beijing and beyond to the north (USGS, 2008d).

Damage to infrastructure included retaining walls, bridges, roads, dams, water pipelines, and tunnels (Free et al., 2008; USGS, 2008b) (Figure 2.6). More than 5.36 million buildings collapsed while 21 million more sustained damage, leaving over 5 million people homeless and 15 million evacuated from damaged homes (USGS, 2008b).

Other historical large and great earthquakes along this fault or nearby faults include a magnitude 7.5 (1933), two magnitude 7.2s (1976), and five magnitude 6-7 events since 1327 AD (Liu-Zeng et al., 2009).

Although the mechanism for intraplate seismicity in the Wenchuan region is not the same as that suspected in the central U.S. NMSZ, the regions share some similarities. Both are within plains regions, somewhat flat expanses with extensive deep sediments. On the Sichuan basin, these sediments are often 6-10 km deep (Robert et al., 2010; Zeng et al., 2014). The extent of the sediment depth across this plains region allows for widespread shaking and low attenuation as expected within the central U.S. A similar upper range of event magnitudes also allows for comparison: both regions have histories of occasional events with upper magnitudes in the 7-8 range. Combined with China's longer historical record and more extensive built environment, Sichuan Basin earthquakes can be used for comparison to current conditions in the central U.S. NMSZ.



Legend

- ❶ New Madrid Seismic Zone
- ❷ Wabash Valley Seismic Zone
- ❸ Anna, Ohio, Seismic Zone
- ❹ Northeastern Kentucky Seismic Zone
- ❺ Giles County Seismic Zone
- ❻ Eastern Tennessee Seismic Zone
- ❼ Charleston, South Carolina, Seismic Zone

Figure 2.1: Seismic Zones near Kentucky. Relative locations of several seismic zones within the central and eastern United States near Kentucky. (Modified from Street and Woolery, 1997.)

Figure 2.2: New Madrid Fault Line. Scarp of the New Madrid Fault Line on the Mississippi River at New Madrid, Missouri (facing approximately west). Inset: Marker sign for the New Madrid Fault, immediately adjacent to the east of photo location. Photos: ©Alice M. Orton 2013.

(a)

(b)

Figure 2.3: Reelfoot Lake, Tennessee. (a) The line of trees in the mid-left background originally marked the edge of a field. Subsidence of the region following the 7 February 1812 New Madrid earthquake caused the area to fill with water. (b) The trees have continued to grow submerged in the resulting lake for 200 years. Photos: ©Alice M. Orton 2013.

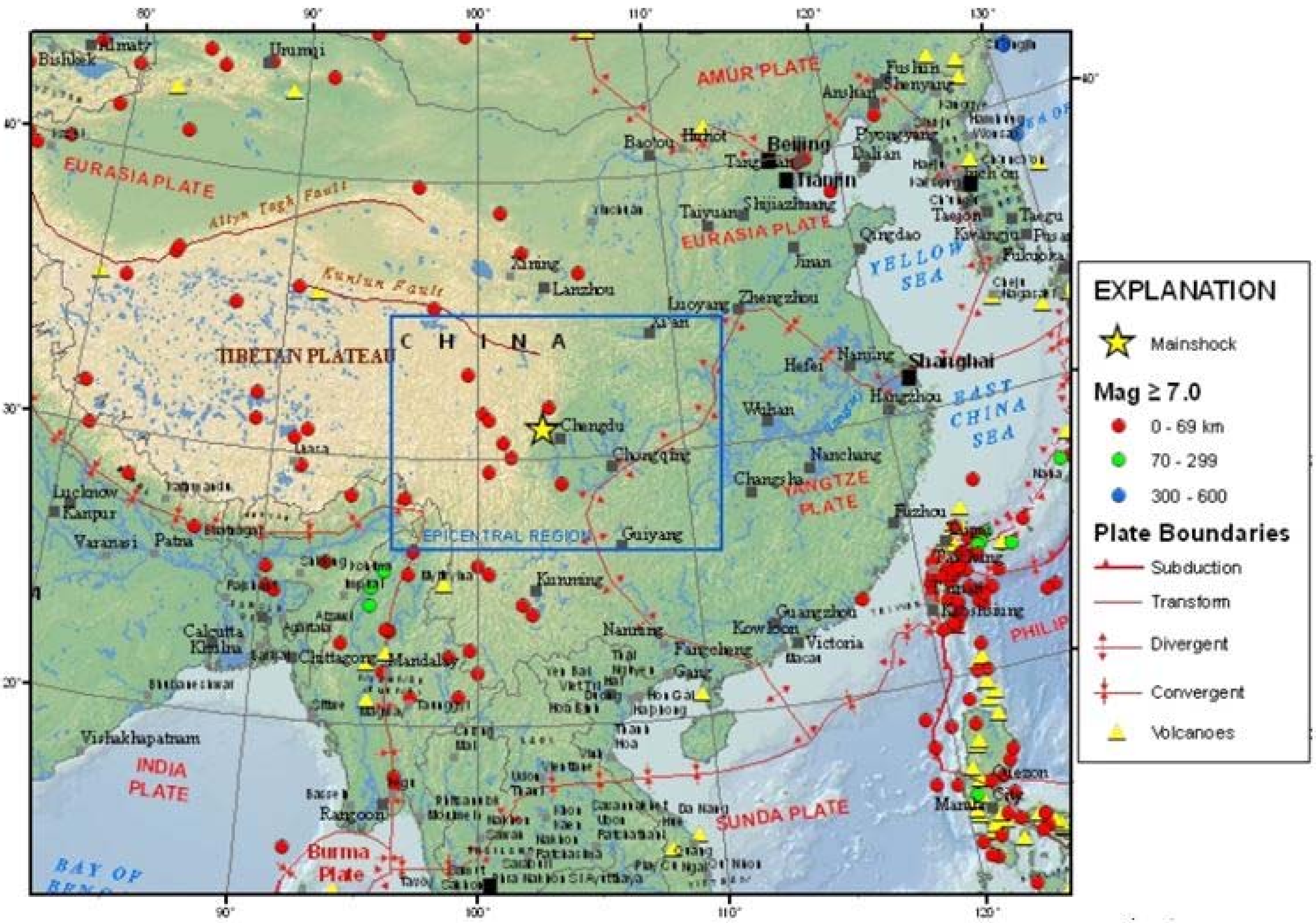


Figure 2.4: Tectonic Setting for the 2008 Wenchuan Earthquake. Tectonic plate boundaries and interactions relevant to the 2008 Wenchuan, China, earthquake. (From USGS, 2008c.)

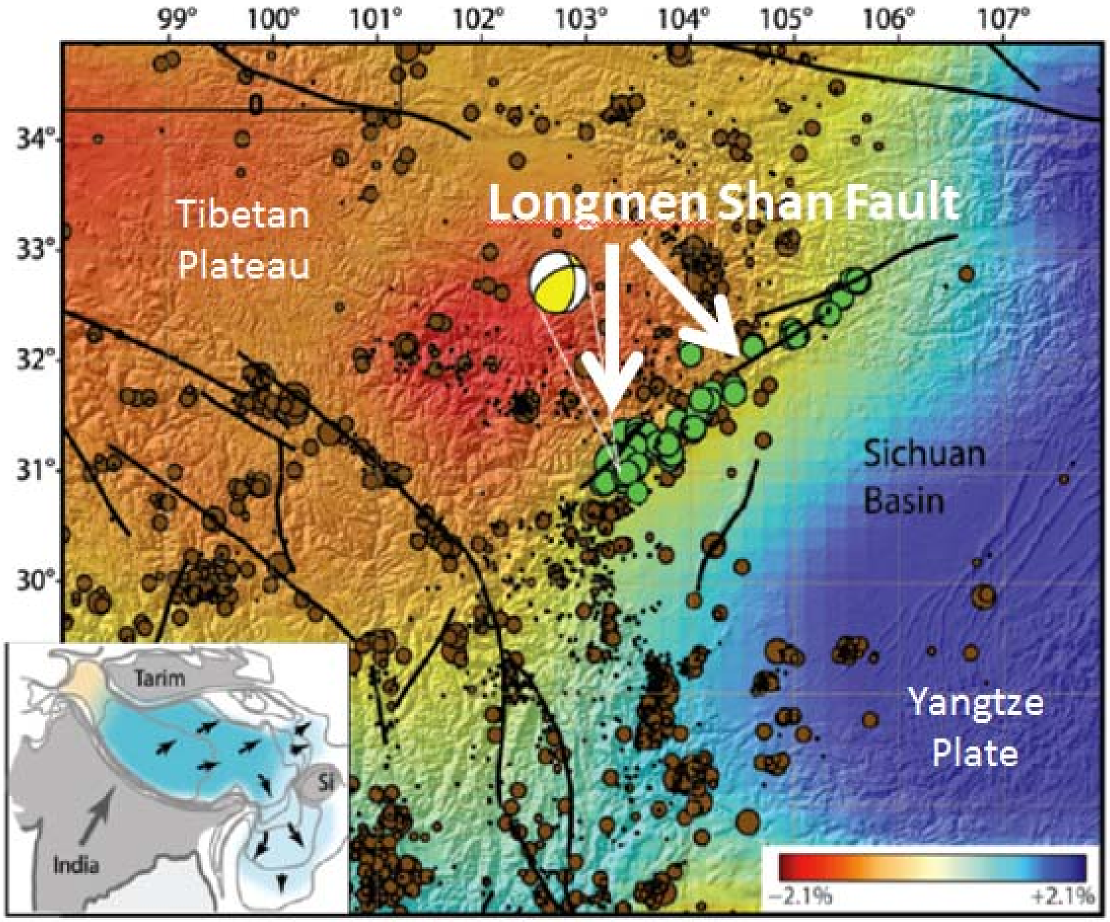


Figure 2.5: Epicenters of the 12 May 2008 Wenchuan Earthquake. Longmen Shan Fault and regional seismicity resulting from the M7.9 Wenchuan earthquake. (From Burchfiel et al., 2008.)

(a)

(b)

Figure 2.6: Bridge Damage from the 12 May 2008 Wenchuan Earthquake. Examples of damage to bridges in the Wenchuan, China, area caused by the 12 May 2008 Wenchuan earthquake. Photos: ©Zhenming Wang 2008.

CHAPTER 3: METHODOLOGY

3.1 Collection of Ground Motion Data

A literature review was conducted to determine the estimated magnitudes, locations and depths of the three main great earthquakes in the 1811-1812 New Madrid sequence. Sources included the USGS Earthquake Catalog (Peterson et al., 2008) and several often referenced older as well as newer publications (Nuttli, 1973; Johnston and Schweig, 1996; Hough et al., 2000; Bakun and Hopper, 2004; Cramer and Boyd, 2011; Hough and Page, 2011). A database was compiled indicating the event date; estimated location, magnitude and depth; and source reference. This database was later used to create the seismic hazard scenarios for scientific and relative economic analyses.

3.2 Identification of Western Kentucky Science-affected Economic Issues

In an effort to determine the science knowledge base and ascertain the effect of current seismic hazard mitigation policies on western Kentucky economy, a series of informal interviews was arranged with a wide variety of professionals whose work could potentially bring them in contact with seismic hazard mitigation policies and their effects. A total of 29 interviews were conducted in Lexington, Frankfort, Paducah, Calvert City, and Murray, Kentucky, or by phone with individuals unable to meet in person. With the permission of each participant, the interviews were recorded for later review. Table 3.1 gives interview participants' occupational industries and jurisdictional levels. Several participants hold positions that overlap industries, such as emergency management and education, or transportation and engineering, and have therefore been counted twice.

A standard list of questions was provided in advance when possible to each interviewee. However, questions asked in each interview reflected the jurisdictional level, position, responsibilities, experience, and knowledge regarding earthquake mitigation policies of the specific interviewee. Follow-up and follow-on questions were often asked based on information received during the course of the interview. The standard (original) interview questions are attached as Appendix A.

3.3 Review of Chinese Mitigation Policy

During a Summer 2013 visit to Gansu and Ningxia Provinces, People's Republic of China, researchers from the Kentucky Geological Survey were allowed to tour the

Lanzhou Institute of Seismology, the Gansu Province Emergency Response Center, the Gansu Base for Land Training Operations (Earthquake Recovery Center training facility), the Ningxia Earthquake Center, the Haiyuan 1920 Earthquake Museum (Ningxia Province) and fault scarp, and one of the Ningxia Province seismic stations. In-field observations were made of the Haiyuan earthquake (magnitude 7.8-8.5, December 1920) fault scarp and vicinity including recent (post-2008) changes to residential building technology and infrastructure. Visits to the 2008 Wenchuan fault scarp and impact areas were planned but unable to be carried out due to the occurrence of the 21 July 2013 magnitude 5.9 Minxian, Gansu Province, China, earthquake, rescue efforts for which took priority over field visits.

Documents regarding seismic hazard mitigation policies at the Chinese national and provincial levels were obtained through the assistance of the Lanzhou Institute of Seismology (LIS), Lanzhou, Gansu Province, China. Some documents were already in English. Documents in Chinese were translated, either partially or in whole, by Qian Li of the LIS and by Dr. Zhenming Wang of the Kentucky Geological Survey. These documents covered seismic hazard mitigation before the 2008 Wenchuan earthquake, changes made to public policy as a result of that event, and several examples of rebuilding projects undertaken as recovery efforts. Documents included the Ministry of Construction’s National Standard Code for Seismic Design of Buildings (2001 and 2010); National Standard Seismic Ground Motion Parameter Zonation Map of China (2001 and 2008); Emergency Response Law of the People's Republic of China (2007); Law of the People’s Republic of China on Protecting Against and Mitigating Earthquake Disasters (2008) and summary of changes from previous law; Regulations on Post Wenchuan Earthquake Restoration and Reconstruction (2008); and examples of reconstruction projects following the 2008 Wenchuan earthquake. A literature review of these documents was conducted to ascertain applicable building code and emergency management policy changes.

3.4 Creation of NMSZ Seismic Hazard Scenarios

A set of 36 earthquake hazard scenarios was created using FEMA’s Hazus-MH software based on the historical NMSZ earthquakes database created earlier. Although it would have been preferred to create fault line scenarios, Hazus does not include fault line data for any area east of the Rocky Mountains. Unless customized databases are input by the user, only point-source scenarios are available for modeling within the NMSZ.

Variables for the point-source hazard scenarios were limited to the following four categories:

(3) Locations (latitude/longitude) of the 1811-1812 main shocks

- 16 December 1811: 36.0, -90;
- 23 January 1812: 36.3, -89.6; and
- 7 February 1812: 36.5, -89.6

(2) Focal depths (above and below the regional 15 km depth limit)

- 10 km, and
- 20 km

(3) Magnitudes (at the lower, middle and upper best estimates for each historical event based on literature review)

- 16 December 1811: M7.2, M7.7 and M8.2 ;
- 23 January 1812: M7.1, M7.5 and M7.9; and
- 7 February 1812: M7.4, M7.8 and M8.1

(2) Ground motion attenuation functions

- Atkinson and Boore's revised attenuation function for eastern North America (denoted A&B 2006) (Atkinson and Boore, 2006), and
- the Central & East U.S. combined ground motion characterization model (denoted CEUS 2008), developed using weighted input from other attenuation functions (FEMA, 2012b)

Manipulation of these four variables created a total of 36 point-source hazard scenarios. Additionally, in order to compare with the USGS historical fault line scenario (New Madrid SW M7.7 Scenario) and NSHM, two additional hazard scenarios were created for the 16 December 1811 location, M7.7, at 0 km depth, also using the two ground motion attenuation functions listed above. Although a 0 km-depth event is physically impossible, these scenarios were created for this particular location and magnitude to bracket the 10-km depth fault line scenario with point-source scenarios at 20 km and 0 km. This brought the total point hazard scenario count to 38.

One additional scenario was created to utilize the USGS New Madrid SW M7.7 Scenario fault line data. This scenario was developed to model ground motion from the southwest fault segment of the 1811-1812 earthquakes (the 16 December 1811 event) (D. Bausch, personal communication, 2014) for emergency management purposes. The hazard scenario differs in several ways from the previous 38 scenarios. First, it is for a fault line hazard rather than a point-source hazard, so resulting contour maps show the northeast-southwest trend expected along the major fault strike. Next, the contour maps were created by a modeling team and subsequently input into Hazus as a user-defined scenario, rather than allowing Hazus to create ground motion contour maps. This requires that the hazard parameters of location (fault line), attenuation function, magnitude, and depth are pre-determined and specific to the supplied contour maps. The hazard scenario parameters cannot be modified within Hazus without the user supplying a new set of contour maps for the new scenario parameters. For the USGS data supplied, a magnitude 7.7 earthquake event at 10 km depth was specifically modeled. The fault location incorporated points between (35.537, -90.39) and (36.3, -89.5). Additionally, the attenuation function was specified by the model rather than selected within Hazus. Per model documentation, Boore et al. (1997) is the standard attenuation model for ShakeMap peak ground acceleration (PGA), spectral acceleration at 0.3 seconds (SA 0.3), and spectral acceleration at 1.0 seconds (SA 1.0) calculations. However, it should be noted that this attenuation function was developed for western North America rather than central or eastern North America and may therefore not be as appropriate as an attenuation function developed specifically for the NMSZ. Refer to scenario metadata (USGS, 2011) for additional information about the ShakeMap model.

The Federal Emergency Management Agency's (FEMA's) Hazus-MH Earthquake Model software, version 2.1 SP1, (hereafter referred to as Hazus) was used to generate ground motion contour maps for PGA, SA 0.3 and SA 1.0 values for each of the historical point hazard scenarios above. The scenario variations and naming scheme are defined in Table 3.2. Instructions for recreating the Hazus scenario models are included in Appendix B.

3.5 Formulation of Economic Analyses

Hazus software was also used to generate a relative economic analysis for each of the seismic hazard scenarios. The software package includes databases for each state containing estimates of building types within each census tract; locations of critical facilities such as police and fire stations, hospitals, schools, and utilities; and population data based on U.S. census figures (FEMA, 2012b). At the discretion of the user, these default databases can be used during the economic analysis step, or the databases can be modified or replaced with more specific local data if it is available. For the purposes of this study, the included databases were used without modification so that analysis results were, to the best of our ability, consistent with results which would be generated by a federal agency.

Within Hazus, a standard geographic study region was created containing 178 counties in 7 states along the central NMSZ, set to calculate analyses at the census tract level for the finest possible display allowed by the software. This region was then used for all scenarios so that each resulting economic analysis would be calculated for a standardized geographic area. Figure 3.1 illustrates the region selected for the Hazus analyses. A list of the states and counties included in the base region is given in Appendix C.

The region was then duplicated and a hazard scenario specified for each model. An historical epicenter event scenario was created indicating the appropriate historical event location, attenuation function, magnitude, and depth for each model. Within Hazus, historical epicenter events east of the Rocky Mountains are all specified as point-source locations rather than fault line hazard sources, so contour maps expand circularly from the designated point source rather than in an oblong shape from a fault line source. These scenarios are specifically intended for deterministic seismic hazard analysis (DSHA) rather than PSHA (FEMA, 2012c) and do not account for return periods or exceedance probabilities.

Hazus software allows analysis of individual economic factors, such as damage to buildings, infrastructure, utilities, etc. For this study, an analysis of each hazard scenario was run for all possible analysis modules.

A Global Summary Report was generated for each hazard scenario from analysis results. The Global Summary Report is a standardized report that Hazus can generate from the results of any analysis. It contains information about the hazard scenario parameters as well as summary information from the analysis including direct and induced damage to buildings, critical facilities, transportation routes, and utility lifeline facilities; estimates of injuries and casualties based on building occupancy for various times of the day; and projected economic losses.

In addition to the 38 point-source hazard scenarios, one additional economic analysis was run using the ShakeMap data supplied by the USGS for the New Madrid SW M7.7 Scenario (identified as SW Fault 1 in Table 3.2). Economic analyses were run for all analysis modules for the fault hazard event and a Global Summary Report was created as for the 38 point-source hazard scenarios.

Table 3.1: Interview Participant Occupations

	Jurisdictional Level				
Industry	**Private/ Contractor**	**City Gov't**	**County Gov't**	**State Gov't**	**Federal Gov't**
Building/Real Estate Development	3	1	1		
Economic Development	1	2		1	
Education				2	
Energy	1			2	2
Engineering	3	1		3	2
Finance/Insurance	2				
Health Care	3				
Safety/Emergency Management	4			2	1
Seismology/Science				1	1
Transportation				2	
Waste Management				1	

Table 3.2: NMSZ Seismic Hazard Scenarios

		Variables Modified for This Study					
Scenario ID (X #### ## ##)	**Date of Historic Event (MM-DD-YYYY)**	**Attenuation Function† (X #### ## ##)**	**Hazus eqEpicenterID* (X #### ## ##)**	**Magnitude (M) (X #### ## ##)**	**Depth (km) (X #### ## ##)**	**Latitude (degrees)**	**Longitude (degrees)**
A 4026 72 10	12-16-1811	A&B 2006	4026	7.2 (default)	10 (default)	36 (default)	-90 (default)
C 4026 72 10	12-16-1811	CEUS 2008 (default)	4026	7.2 (default)	10 (default)	36 (default)	-90 (default)
A 4026 72 20	12-16-1811	A&B 2006	4026	7.2 (default)	20	36 (default)	-90 (default)
C 4026 72 20	12-16-1811	CEUS 2008 (default)	4026	7.2 (default)	20	36 (default)	-90 (default)
A 4026 77 00	12-16-1811	A&B 2006	4026	7.7	0	36 (default)	-90 (default)
C 4026 77 00	12-16-1811	CEUS 2008 (default)	4026	7.7	0	36 (default)	-90 (default)
A 4026 77 10	12-16-1811	A&B 2006	4026	7.7	10 (default)	36 (default)	-90 (default)
C 4026 77 10	12-16-1811	CEUS 2008 (default)	4026	7.7	10 (default)	36 (default)	-90 (default)
A 4026 77 20	12-16-1811	A&B 2006	4026	7.7	20	36 (default)	-90 (default)
C 4026 77 20	12-16-1811	CEUS 2008 (default)	4026	7.7	20	36 (default)	-90 (default)
SW Fault 1	12-16-1811	B 1997	4026	7.7	10	(fault line)	(fault line)
A 4026 82 10	12-16-1811	A&B 2006	4026	8.2	10 (default)	36 (default)	-90 (default)
C 4026 82 10	12-16-1811	CEUS 2008 (default)	4026	8.2	10 (default)	36 (default)	-90 (default)
A 4026 82 20	12-16-1811	A&B 2006	4026	8.2	20	36 (default)	-90 (default)
C 4026 82 20	12-16-1811	CEUS 2008 (default)	4026	8.2	20	36 (default)	-90 (default)
A 4027 71 10	01-23-1812	A&B 2006	4027	7.1 (default)	10 (default)	36.3 (default)	-89.6 (default)
C 4027 71 10	01-23-1812	CEUS 2008 (default)	4027	7.1 (default)	10 (default)	36.3 (default)	-89.6 (default)
A 4027 71 20	01-23-1812	A&B 2006	4027	7.1 (default)	20	36.3 (default)	-89.6 (default)
C 4027 71 20	01-23-1812	CEUS 2008 (default)	4027	7.1 (default)	20	36.3 (default)	-89.6 (default)
A 4027 75 10	01-23-1812	A&B 2006	4027	7.5	10 (default)	36.3 (default)	-89.6 (default)
C 4027 75 10	01-23-1812	CEUS 2008 (default)	4027	7.5	10 (default)	36.3 (default)	-89.6 (default)
A 4027 75 20	01-23-1812	A&B 2006	4027	7.5	20	36.3 (default)	-89.6 (default)

Table 3.2: NMSZ Seismic Hazard Scenarios (cont.)

		Variables Modified for This Study					
Scenario ID (X #### ## ##)	**Date of Historic Event (MM-DD-YYYY)**	**Attenuation Function† (X #### ## ##)**	**Hazus eqEpicenterID* (X #### ## ##)**	**Magnitude (M) (X #### ## ##)**	**Depth (km) (X #### ## ##)**	**Latitude (degrees)**	**Longitude (degrees)**
C 4027 75 20	01-23-1812	CEUS 2008 (default)	4027	7.5	20	36.3 (default)	-89.6 (default)
A 4027 79 10	01-23-1812	A&B 2006	4027	7.9	10 (default)	36.3 (default)	-89.6 (default)
C 4027 79 10	01-23-1812	CEUS 2008 (default)	4027	7.9	10 (default)	36.3 (default)	-89.6 (default)
A 4027 79 20	01-23-1812	A&B 2006	4027	7.9	20	36.3 (default)	-89.6 (default)
C 4027 79 20	01-23-1812	CEUS 2008 (default)	4027	7.9	20	36.3 (default)	-89.6 (default)
A 4028 74 10	02-07-1812	A&B 2006	4028	7.4 (default)	10 (default)	36.5 (default)	-89.6 (default)
C 4028 74 10	02-07-1812	CEUS 2008 (default)	4028	7.4 (default)	10 (default)	36.5 (default)	-89.6 (default)
A 4028 74 20	02-07-1812	A&B 2006	4028	7.4 (default)	20	36.5 (default)	-89.6 (default)
C 4028 74 20	02-07-1812	CEUS 2008 (default)	4028	7.4 (default)	20	36.5 (default)	-89.6 (default)
A 4028 78 10	02-07-1812	A&B 2006	4028	7.8	10 (default)	36.5 (default)	-89.6 (default)
C 4028 78 10	02-07-1812	CEUS 2008 (default)	4028	7.8	10 (default)	36.5 (default)	-89.6 (default)
A 4028 78 20	02-07-1812	A&B 2006	4028	7.8	20	36.5 (default)	-89.6 (default)
C 4028 78 20	02-07-1812	CEUS 2008 (default)	4028	7.8	20	36.5 (default)	-89.6 (default)
A 4028 81 10	02-07-1812	A&B 2006	4028	8.1	10 (default)	36.5 (default)	-89.6 (default)
C 4028 81 10	02-07-1812	CEUS 2008 (default)	4028	8.1	10 (default)	36.5 (default)	-89.6 (default)
A 4028 81 20	02-07-1812	A&B 2006	4028	8.1	20	36.5 (default)	-89.6 (default)
C 4028 81 20	02-07-1812	CEUS 2008 (default)	4028	8.1	20	36.5 (default)	-89.6 (default)

† Three attenuation functions are used. For the point hazard models, CEUS 2008 refers to the composite attenuation function developed for the U.S. Geological Survey (USGS) for use in the National Seismic Hazard Maps and is designated "C" in the Scenario ID; while A&B 2006 refers to Atkinson and Boore (2006) and is designated "A" in the Scenario ID. For the single fault hazard model, B 1997 refers to Boore et al. (1997), which is the attenuation function employed by the USGS in their ShakeMap models (USGS, 2008e).

* Hazus eqEpicenterID: This number refers to the historical event identification number assigned by the USGS and used in the Hazus-MH software to indicate a specific earthquake event.

HAZUS NMSZ Central Counties Region

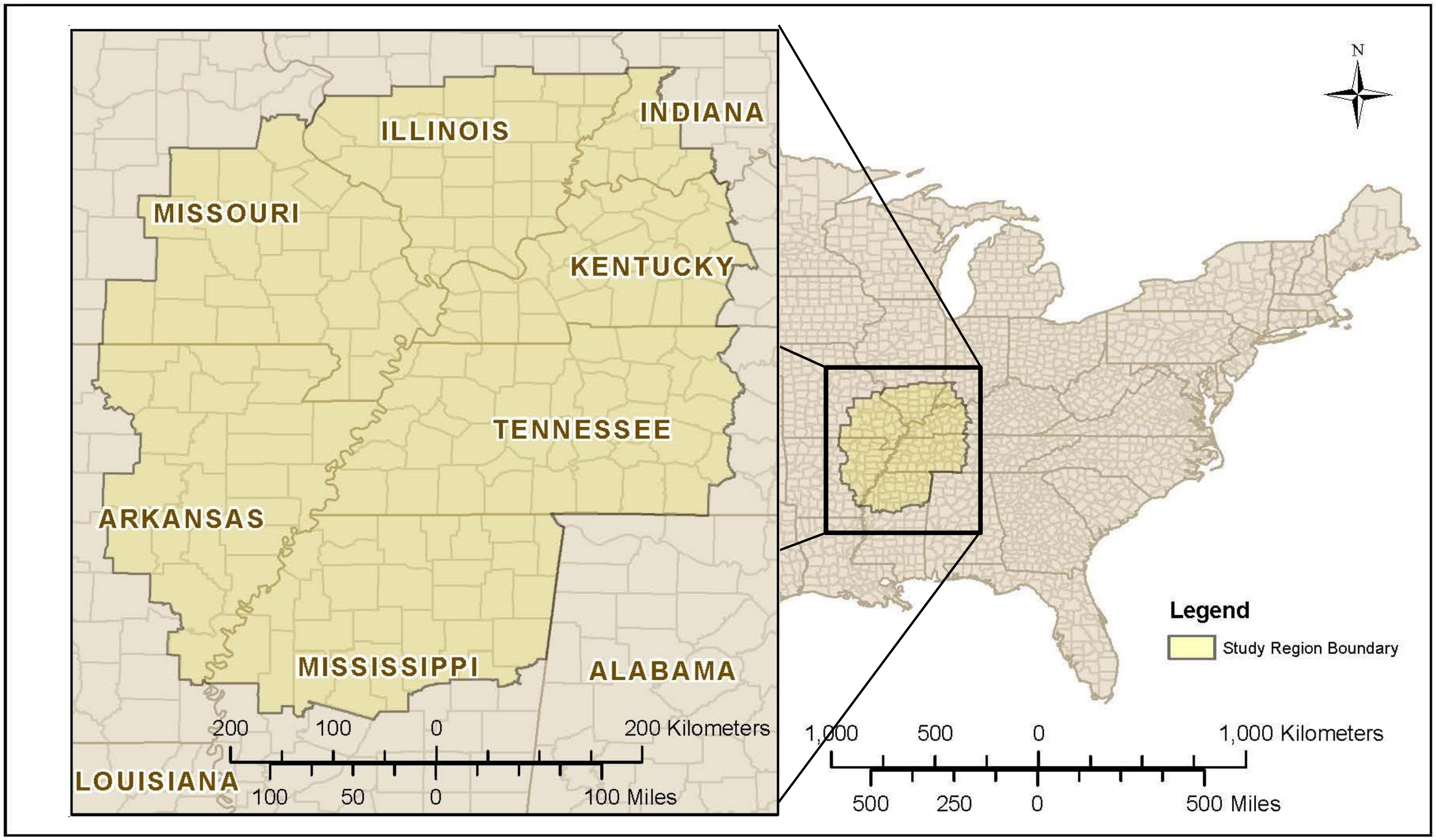


Figure 3.1: Hazus Study Region. Map of the area included for each Hazus economic analysis. See Appendix C for a listing of states and counties within this study region.

CHAPTER 4: RESULTS

4.1 Interviews

4.1.1 General knowledge

A total of 29 interviews were conducted to assess general knowledge of underlying science and related economic concerns for western Kentucky. Out of 15 interviewees with non-science or engineering backgrounds, 10 had little or no information about the actual seismic hazard for the New Madrid Seismic Zone (NMSZ), western Kentucky, McCracken County, or the City of Paducah. Their knowledge was a broad collection of what they have read in newspaper accounts, heard from others, or experienced themselves while living in the region. Several had expectations of catastrophic events, although they were not specific about details. Four non-science background respondents had some sense of the actual hazard estimates, having explored the subject through personal or job related interest, while one non-science interviewee had solid technical knowledge through job-related training. Among the 14 interviewees with scientific backgrounds, 7 respondents (just half) had solid technical knowledge, while 4 had some knowledge of local earthquake hazard and 3 had only little or anecdotal information.

Expectations of a maximum magnitude earthquake within the non-science group ranged from 6.0 to 8.1, with 9 of the 15 respondents not answering or claiming no knowledge of this information. Several participants indicated that the general sense was that disaster could be expected, but they didn't know any details. The expected source of earthquake hazard was the NMSZ, according to 12 of these participants. Four participants also had knowledge of the Wabash Valley Seismic Zone, and one could name several surrounding seismic zones that might contribute to local or regional earthquake hazard. One respondent knew generally that the earthquake hazard source was "near the river." Two respondents claimed no knowledge of the source for earthquake hazard.

The range for maximum magnitude earthquakes given by the group with scientific backgrounds was surprisingly broader than that given by those with non-science backgrounds, extending from >6.0 to 8.5, although this group was much more likely to qualify their responses with information about the earthquake source or the recurrence interval. Several of these respondents skirted the issue by citing what they knew of historic events rather than giving a firm expectation for future events; and five of them didn't answer this question. Within this group, the NMSZ was given as the most likely earthquake hazard source (10 times out of 14), but 7 respondents also named other regional seismic zones as potential sources, including the Wabash Valley Seismic Zone; the Rough Creek Graben; the Charleston, Missouri, region; the Eastern Tennessee Seismic Zone; the Maysville/Sharpsburg region; the northeast Kentucky region; the southeast Kentucky region; the Charleston, South Carolina, region; and the Reelfoot Fault. A few answers were slightly more vague, including "40 to 50 miles away" and "to the west."

The non-science group had little understanding of expected earthquake recurrence intervals, with only one respondent giving actual statistical expectations of given magnitude in a given time range. A few interviewees with scientific backgrounds had more knowledge (sometimes very specific due to the nature of their occupations) on seismic hazard for the region, but return period estimates ranged widely, from magnitude 8 in 200-500 years to magnitudes 8-8.5 in 2500 years, with non-specific magnitude great earthquake estimates of 500 years and moderate earthquakes within 100 years.

Among non-science-based interviewees, "experts" was a broad category that included scientists (non-specific), engineers (non-specific), federal government agencies (USGS and U.S. Department of Energy), state geologists (Kentucky Geological Survey), and research universities (Murray State University). Two of these respondents gave the name of a person they considered to be an expert, while five did not respond to this question. Whether the response was general or specific, the underlying feeling was one of great trust in these experts. Among those with scientific backgrounds, there was approximately the same response level, with four participants not responding to this question. The other 10 interviewees, however, were much more likely than the non-science participants to indicate at least one source of expert information, some general and some more specific, including seismologists or seismic consultants (non-specific), geologists (non-specific), engineers (non-specific), architects (non-specific), the American Association of State Highway and Transportation Officials (AASHTO) engineers, federal government agencies (USGS and U.S. Department of Energy), the state (Kentucky) Geological Survey, and research universities (University of Tennessee and St. Louis University). Five individuals were specifically named as experts by their science-background peers.

Only one member of the non-science background group claimed never to have seen a copy or a version of the National Seismic Hazard Maps (NSHM), but most had seen them at least once. Four had used the maps, or some product of them, in their work. However, no one in this group claimed to understand the maps, just that the concentric rings indicated higher earthquake danger at the centers and lower danger as the rings expanded. Only a few indicated they were aware there was more than one map, although five in this group indicated they questioned the validity of seismic hazard map(s) for the NMSZ. None claimed any knowledge of the vetting process or that the maps are reviewed and revised on a regular schedule.

Among the science-based interviewees, all had seen the maps but only half (7 of 14) use them or a product of them in their work. Only one respondent claimed to trust the maps implicitly. Some of those who used the maps indicated they took other factors such as surface geology, underlying soils, other load sources (wind, thermal contraction), and other earthquake source areas into consideration when determining earthquake hazard rather than relying implicitly on the NSHM series. Several of these respondents indicated they were more likely to consider DSHA scenarios for individual projects than relying on the general PSHA scenarios given on the maps. Most, however, took the view that the science is what it is and they accept it as fact, or as close to fact as we can get at the moment. They have been given a formula for implementing the science in accordance with current local, regional or federal policies, such as building codes, and they do not spend time questioning either the formulae or the underlying science. As a group, they do not worry about the difference between models and actual data. Only a few engineers know or care to know anything about the NSHM series development process. They are caught in a no-man's land where their clients demand knowledge and expect absolute answers. Because engineers risk their livelihoods and reputations on their approval of construction plans, they calculate building and structural requirements based on engineering design codes (such as ASCE/SEI 7-10 and AASHTO standards), then fall back on the expertise behind those codes and the authority of current design policies if anything goes wrong.

The response of this group to questions of earthquake preparedness tended to divide less by science vs. non-science background and more by whether individual respondents deal with the public on a mass basis or on an individual basis. For example, those in positions of responsibility for health care facilities or public emergency response or education tended to have well-defined organizational emergency response plans in place that are reviewed and revised on a regular basis. Many of these respondents rely on the advice of experts since the underlying science is unclear or unavailable to them in a simple form. In defining emergency response, the meaning is usually applied to emergencies resulting from any natural hazard (flood, wind, fire, earthquake, ice, etc.); seismic hazard is not specifically addressed in most cases, but is just one of many hazard possibilities to be considered. One participant specifically asked why, if the seismic hazard is so extreme, there is not more focus by government agencies to prepare for a large earthquake event other than earthquake-resistant structural requirements. Some organizations also have plans in place for response to terrorism or other anthropogenic sources (fire, large-scale accident, etc.). Those who deal with the public on an individual basis and those who do not deal with the public tend to either not know about or not have emergency response plans in place.

Science-based respondents as a rule had little to say about earthquake preparedness since as a group they deal less with the public, although there were a few with responsibility for large facilities that had specific hazard response plans in place. Individuals may or may not have personal preparations in order, but those whose work emphasized emergency preparedness tended to also have developed personal emergency plans.

Several interviewees indicated they had seen a surge in emergency preparedness following a severe ice storm in western Kentucky in 2009, although the verdict was split about whether there can really be enough preparedness. Respondents in both groups generally agreed that human beings cannot prepare for every natural hazard: no amount of preparation will ultimately stave off every possible danger. Most participants were in agreement that at some point, society and individuals choose which dangers are of most concern to them, determine how best to protect themselves, and then live with the consequences. Several participants expressed that these decisions are paramount to intelligent living and that individuals should be accountable for their personal choices of living environments.

4.1.2 Concerns regarding public policy

There was a range of responses to questions about public policy. At one end of the spectrum were those who trust the experts and believe that public policies are in place for the general good, so those with less knowledge should not question them. At the other end of the spectrum were those who question whether the science justifies current public policies. If the science is flawed (over- or understated hazard, or uncertainty in models), then current policies may not be appropriate. Several respondents would like better scientific information to justify current public policy.

Public policy issues resulting from seismic hazard analysis mostly revolved around building codes and infrastructure engineering. Several interviewees from both science and non-science backgrounds expressed concern that building codes are not regulated evenly, either within the Commonwealth of Kentucky or between Kentucky and surrounding states. In particular, the City of Paducah and McCracken County, Kentucky, seem to have a better system for building construction inspections than surrounding areas. Many respondents stated that companies or individuals who do not want to incur the higher costs associated with seismic design and construction which will be enforced in Paducah and McCracken County simply go to a neighboring county or across the Ohio River into Illinois where building codes are either less stringent or will not be enforced. One interviewee was careful to distinguish that he was aware of this happening for residential building, but not for commercial building which is more closely regulated.

A second policy concern was that federal agencies apply different standards, codes or rules than local or state agencies do. Many federal agencies have jurisdiction for their own building codes and hazard mitigation requirements, but these requirements have to be met within the local areas where federal projects are built. One example was the Paducah Gaseous Diffusion Plant (PGDP), operation of which is regulated by the federal Nuclear Regulatory Commission (NRC). Due to the current seismic hazard rating assigned to western Kentucky by the NSHM, upgrade of the existing PGDP facilities to meet federal hazard mitigation requirements have been deemed too costly and the operation is to be relocated out of the area. Local government officials, businessmen, and even engineers question whether the science supports this decision. They do not see compelling evidence of conclusions of high earthquake hazard for the region, regardless of conclusions of the NSHM committee. Perception is that federal agencies are not concerned about local issues or how federal decisions affect local regions. There is strong local feeling that doing the science is not enough. When the science is inconclusive, the scientists are responsible for saying so.

Additionally, there was some local concern that federal government officials often put local areas in political limbo by not making decisions. When an issue is inconclusive, it is a simple thing for the matter to be put on hold, awaiting further investigation, further funding, or even a better political climate before resolution. But this delay often hampers local business decisions. If a decision were made at the federal level, then local matters could progress; but a lack of decision just hangs the process.

Another concern that was voiced during the interview process was that of appropriate representation. Because earthquakes happen less frequently in western Kentucky, there are fewer local experts who focus on this issue. This translates into less representation at a federal level when issues involving this expertise arise. One example given was in regard to the AASHTO code decision process. A respondent indicated that AASHTO codes are created by a voting process. Since states with more earthquake experience have more to say about the associated hazard, their opinions are more likely to get carried into the code development process. States with less exposure to seismic hazard trust the opinions and advice of experts from states that have more exposure. States in which the hazard is assumed to be high but the recurrence of seismic events is low are therefore underrepresented during building code decisions.

A related issue to representation was that of political or personal agenda. Many respondents commented on the relationship between personal or political agendas and the ability of individuals to manipulate outcomes where the science was less than conclusive. Respondents were of two distinct opinions: those who felt politics should have nothing to do with seismic hazard mitigation decisions, and those who felt that the two issues were unequivocally connected. One federal science representative who was very knowledgeable of the process used to develop and revise the NSHM series stated that the process takes into account the best science available at the moment and gives fair representation to both supporting and opposing views prior to release of map updates. A state-level science-based respondent indicated concern that policy gets muddied by people who want a particular outcome rather than "the truth," and that some political decisions are driven by hidden agendas, not science. Another similarly commented that the issues are so complex that they are difficult for non-experts to understand. For scientists and government officials, it is increasingly easy to ignore the issues they do not want to discuss and just pick the perspective they like. A state-level public official commented that how policy makers feel about an issue sometimes has more to do with their decisions than actual facts about the issue. A private-sector engineer responsible for site response investigation for a federal project commented that there was some political push to have their independent results match the federal expectations. A western Kentucky respondent commented that it is not for policy makers to influence the seismic hazard determination since they are not experts on the science. On the other side of the argument, several local businessmen felt that if the science wasn't definitive, then any policy decisions based on it were arbitrary and certainly should take into consideration other factors, such as how policy decisions based on that science would affect the local economy. Clearly, this interaction between science and policy decisions is of key importance when the science is indecisive.

Taking responsibility for policy decisions was also mentioned as an area for concern. The general consensus of several respondents was that although most professionals who are affected by seismic hazard mitigation policy would prefer less micromanagement, no one wants to be the person responsible for downgrading the seismic hazard rating. Because the science is uncertain – because we don't know enough about historical seismicity in western Kentucky or the potential for future seismicity – it is possible that a large or great earthquake will occur in or near this area. Even those who do not want to believe this generally acknowledge that the possibility exists. In which case, no individual wants to be the one to take personal responsibility for downgrading the federally-sanctioned seismic hazard rating estimates. No one wants to be responsible for the outcome if people die as a result of less stringent building requirements. Opinions included that it is right to take precautions, that if people are smart they learn from other people's mistakes, and that the current status quo is the best that can be done right now. However, another interviewee quipped that we knew the earth had been hit by meteors in the past, but we do not build for those conditions and we shouldn't be required to build for seismic conditions that have such great uncertainty built in. These concerns for public policy, and ultimately public safety, must be considered against the very real economic cost of implementing earthquake mitigation policies.

4.1.3 Concerns regarding economic development

Not all interviewees had pre-formed opinions regarding the relationship between seismic hazard mitigation and economic development, but all were able to think of some ways that seismic hazard could or did impact social costs. Opinions were split regarding whether the costs were worthwhile. Some felt that any cost was justifiable if lives were saved. One interviewee commented that all the money we spend on education is of no worth if the buildings collapse on the students. He would rather throw the money away on the sensible investment of building reinforcement than live with the consequences if school buildings were built to a lower standard and lives were lost in a collapse. Others stated that the money being used to make buildings safer was not justified without some indication that there was a real risk of loss, of which they felt there was no evidence. There was no financial gain to the additional code requirements: a school cost more but was not safer if built to a higher seismic standard than needed; a house cost more but was not more valuable nor more desirable because it was built to more stringent seismic codes. These interviewees were not aware of each other's comments, but their concerns illustrate the scope of opinions.

Several interviewees with business interests regarding economic development for western Kentucky indicated that a current problem is the perception of putting a business in harm's way. Many respondents, both engineers and public officials, related experiences where businesses were unwilling to risk loss of custom or facilities in the event of a major earthquake. Each project development team has to decide how much risk it is willing to assume, in terms of money, time, and inconvenience. The example was given of a large automobile manufacturing company that briefly considered building a manufacturing plant in Paducah, Kentucky. However, once the company did some research, the purported reason for not locating in Paducah was that the local earthquake and wind hazards were too high and the company would not locate a business there. The interview respondent who relayed this anecdote stated he had never experienced either an earthquake or a tornado in the area and felt the perceived threat was worse than the actual threat, but that made no difference to the decision made by the automobile manufacturer. The bottom line is that many investors will simply not consider establishing a business in a high earthquake hazard zone, similar to not wanting to build in a flood plain or in tornado alley. It is less risky to simply establish a business elsewhere. If the hazard rating is correctly evaluated, this is the best business decision. However, if the high hazard rating currently assigned to western Kentucky is inappropriate, business opportunities are lost in the area as a result. Either way, the hazard evaluation as published on the NSHM series, whether correctly evaluated or not, directly impacts the local economy.

If a business already has a base in the area, it is a simple thing to stay as long as no changes are necessary. If, however, a larger facility must be built, or if a business from outside the area is considering relocating to the area, then the costs associated with building to a high seismic mitigation standard must be considered. These costs include additional environmental studies and site assessments, engineers and building consultants, building supplies, inspection/code enforcement, and infrastructure (roads, bridges, traffic improvements, etc.), plus the additional time to make all the necessary arrangements and complete the additional work. More stringent mitigation policies require more time to comply, and time is money. Estimates of these costs ranged from 1% to 20% by various respondents. Some claimed that the costs were such a norm by now that no one paid them any attention, they were just part of the cost of doing business in western Kentucky. Others claimed that the costs were a major deterrent to new business, and especially big business concerns which would require large capital investments.

Beyond the immediate set-up costs, business maintenance costs were also of concern. Earthquake coverage may be as much as 25% of the cost of residential insurance and 30-50% of commercial insurance costs. All structures financed by local banks in western Kentucky are required to carry earthquake insurance to offset the high local investment ratios in case of loss. Other indirect costs include development of emergency management plans, support of emergency management personnel, and possibly insurance to cover interruption of business, although these costs would also be incurred for other natural hazards and cannot be attributed solely to seismic hazard.

One concern expressed by several individuals was that the region suffers from a lack of jobs that will draw educated young people. Local youth who complete a college education have no ability to stay in the area as there are few jobs requiring advanced education. As one interviewee put it, “And how many fast food places do you need?” (J. Cates, personal communication, 2013). The lack of jobs for educated professionals also affects the loss of jobs down the line as communities need fewer grocery stores, restaurants, gas stations, garbage collectors, school teachers, healthcare providers and other infrastructure service employers and employees. Increased seismic hazard ratings for the region are perceived as causing this inability to draw businesses, to maintain educated professionals, and therefore to support other community service employees.

For many interviewees, awareness was high that funds are limited. Whether in private or public coffers, there is only so much money and each person and agency must use their resources to the best of their ability. Either overstated or understated seismic hazard for the New Madrid Seismic Zone would lead to a misuse of funds in western Kentucky as individuals and public agencies conducted business daily. Several respondents related anecdotal recollections of implementation of the International Building Code in western Kentucky around 2002. The seismic policy had changed so severely that residential construction ground to a near halt while local agencies, engineers and design consultants grappled with the best ways to implement the requirements in ways that were still affordable to individual family budgets. On a public level, projects must be juggled and adjusted to cover the higher seismic mitigation requirements.

Although generally seen as having a negative economic impact, it was suggested by a few respondents that there are also positive economic aspects related to seismic mitigation requirements. For example, one respondent indicated that by having state-level seismic hazard mitigation plans in place, the Commonwealth of Kentucky has access to additional federal emergency funding in the case of a declared state of emergency. Another participant noted that cost savings to residential builders who went to adjoining states or counties might actually be negligible since property taxes were often higher in surrounding areas. Yet another interviewee commented that although mitigation requirements increased building costs, those monies sometimes went back into the local economy in construction materials purchased and jobs created in both building and regulation industries. On a related topic, several participants indicated that they felt certain types of organizations, including engineers and environmental consultants, often benefited economically from heightened earthquake hype and might in some cases promote or uphold high hazard ratings to suit their own interests.

In the end, the biggest economic concern had to do with the costs of enforcing an inappropriate level of earthquake hazard mitigation, either too high or too low. While some respondents felt that in the current state of little to no seismic activity the cost was great to prepare for something that would not happen, others felt that it was better to spend the required funds and have no regrets in case of a great earthquake. Proponents on both sides of this issue, however, acknowledged that we really have no way of knowing what will happen. Mankind cannot build or prepare for every possible hazard, so at some point we make decisions and live with the consequences.

4.2 Hazus Analyses

4.2.1 Ground motion contour maps

Scenario ground motion maps were created using FEMA's Hazus software to depict estimated peak ground acceleration (PGA), 0.3-second seismic acceleration (SA 0.3) and 1.0-second seismic acceleration (SA 1.0) for each of the 38 point-source earthquake scenarios (Table 3.2). Although some contour maps have been included as figures within this section, all other contour maps are included in Appendix D for reference.

Models were run for earthquake depths of 0, 10 and 20 km below ground surface. In all cases, changes in depth for earthquake events of same magnitudes and locations had no effect on the minimum or maximum ground motion values, and therefore no effect on the contour maps. It is unclear whether this was due to calculation functions within Hazus, or whether the shallow depth (0-20 km) is still near enough to the surface to have no change in effect on the ground motion of a particular earthquake event.

For the point-source hazard contour maps, each of the motion variables (PGA, SA 0.3, and SA 1.0) showed consistently larger affected geographic areas and a larger range of acceleration values for the correspondingly larger earthquake magnitudes at each location, as expected. See Figures 4.1 and 4.2 for comparison examples. For PGA, minimum values ranged from 0.007 g to 0.06 g, while maximum values ranged from 1.45 g to 3.31 g for the various models. The geographic areas were correspondingly larger for larger magnitudes, increasing by between 12 and 39 km in diameter for a roughly circular area. These values represent between 20% and 100% increases in affected area diameters for PGA over increasing magnitudes for scenario earthquake events at each location. Due to the squaring of radius for area calculations, these increases represent between 45% and 300% increases in affected geographic areas, with a minimum PGA area increase of 1,093 km^2 and maximum of 3,584 km^2 for the models run. Refer to Table 4.1, Hazus Model Ground Motion Minimum and Maximum Values, for value comparisons.

SA 0.3 minimum values ranged from 0.02 g to 0.21 g, and maximum values ranged from 1.98 g to 5.26 g. Affected geographic area diameters increased between 144 and 201 km, representing 35% to 173% increases in SA 0.3 affected geographic area diameters. These values represent considerably larger changes in affected SA 0.3 areas for increasingly larger magnitude earthquakes, with a maximum increase in area of 146,282 km^2 for the variation in models. The SA 0.3 areas increased between 82% and 647% over the range of earthquake magnitudes modeled.

SA 1.0 minimum values ranged from 0.02 g to 0.27 g, while maximum values ranged from 1.63 g to 5.84 g. As expected, values increased with event magnitude at any given location. Affected geographic area diameters increased between 150 and 287 km, representing 32% to 296% increases in diameters, or between 74% and 1467% increases in areas, with a maximum increase of 172,297 km^2 for model increases in earthquake event magnitude at a single location. It should be noted that some areal increases could not be calculated because they extended beyond the study region boundaries.

Additionally, all ground motion (PGA, SA 0.3 and SA 1.0) values and contours were consistently larger for models using the A&B 2006 attenuation function than for those using the CEUS 2008 composite attenuation function for events of the same magnitude at the same location. See Figures 4.3 and 4.4 for comparison examples. The A&B 2006 attenuation function is based on a single model, while the CEUS 2008 composite attenuation function gives weighted values to probabilities from various attenuation models. In the small number of models run for this study, the results for contours of SA 0.3 and SA 1.0 areas varied dramatically depending on the attenuation model applied. These differences in the contour maps based solely on change of attenuation function with all other variables held equal is a clear illustration of the uncertainty in earthquake hazard models.

The single fault or line hazard model, model ID SW Fault 1, differed significantly from the point hazard models in several ways. First, the contour maps for the fault line model were pre-created and input into Hazus for economic evaluation only. The model variables, including attenuation function, event magnitude, location, and depth were all pre-set, so no direct comparison models could be run by modifying single variable parameters. Hazus was able to generate contour maps only for the purpose of assigning ground motion values to the various census tracts. These maps generally follow the contours of the input data sets as expected, with slight variations to account for the differences between actual input contours versus size of individual census tracts. The census tract-based contour maps incorporate blocks of area for a given ground motion value, and therefore have blocky rather than smooth contour boundaries. Since each census tract must be assigned a single value for each ground motion parameter, the contours on the Hazus-generated census tract contour maps varied either larger or smaller than the original contour boundary by the amount of the size of a given census tract. Because these census tract contour maps are basically a restatement of the input contour maps provided by the USGS, they have not been included for further discussion or analysis.

The only real comparison that could be made, then, to the USGS fault line hazard scenario was of the point hazard scenarios at the same location and at the same earthquake magnitude. The six models for event ID 4026 with magnitude 7.7 at 0, 10 and 20 km depth and using both A&B 2006 and CEUS 2008 attenuation models were used for this purpose (model IDs A 4026 77 00, C 4026 77 00, A 4026 77 10, C 4026 77 10, A 4026 77 20, and C 4026 77 20). As indicated previously, variation of depth made no difference to the resultant ground motion values and contour maps, leaving only the attenuation model differences and the difference between point and line sources for comparison. See Figures 4.5, 4.6 and 4.7 for comparison examples.

The pre-assigned minimum value for each ground motion variable in the fault line model was 0.02 g, where the point-source scenario minimum values were lower for PGA for each attenuation model, but higher for SA 0.3 and SA 1.0 for each attenuation model. In the case of the A&B 2006 point-source scenarios, the SA 1.0 minimum was more than twice the value of that assigned for the SW Fault 1 scenario. Maximum ground motion values were consistently higher for the point-source models than for the fault line model, sometimes three to four times more.

In addition to the expected result of oblong rather than circular ground motion contours for the fault line scenario, the differences in minimum and maximum ground motion values resulted in extreme variations between contour diameters and patterns. Although some of this difference can be attributed to the differences in attenuation models used, it is also possible that the fault line model reflected additional information about underlying geology and soils not included in the standardized Hazus ground motion contour maps. If so, the additional soils information should ultimately contribute to better constrained model results.

4.2.2 Global Summary Reports

The Global Summary Reports generated by Hazus give a variety of estimated physical and economic results for each given earthquake hazard scenario. These reports were generated using only the background databases included with the Hazus software; no modifications were made to account for changes since the last database updates or specific information for any locale. Physical estimates of results included damage to buildings, infrastructure and utility systems, and human casualty and injury scenarios for three different times of day to account for general population movements. Economic cost estimates included values of building, infrastructure and utility system losses, and income and capital investment losses. The range of estimates of damages reflected the range of event magnitudes as well as the wide differences in attenuation function results. The severity of A&B 2006 attenuation function results for contour maps was similarly reflected in the physical and economic summary reports, with A&B 2006 results consistently showing much higher loss estimates than CEUS 2008 attenuation function scenarios for events at the same locations and magnitudes. A selection of Global Summary Report results has been included in Table 4.2. One example report is included in its entirety in Appendix E, while the remaining Global Summary Reports are linked to this document as separate electronic files (see List of Files).

Report results for the single fault line model have been incorporated with results for the point-source models. SW Fault 1 results were much closer to those using the CEUS 2008 attenuation function than to results using A&B 2006 for the same location and magnitude event.

For the study region of NMSZ central counties, there was an estimated population of 6,841,567, with 2,074,400 single family residences. In the best case scenario, human casualty estimates were as low as 70 deaths, while the worst case estimate was 14,784 deaths. Casualty estimates were almost always higher in the mid-afternoon, while life-threatening injury estimates were higher in the evening. The lowest casualty and injury estimates occurred during morning hours in every case.

In the best case scenario, fewer than 8% of single family residences sustained any damage, and only 1,753 (0.08%) sustained complete damage. In the worst case scenario, however, as many as 67% of single family residences sustained some damage, with 182,782 (8.8%) sustaining complete damage. Regarding potable water resources, the best case scenario estimated 20,299 of 2,634,125 households in the region without water service on day 1 (< 1%), while the worst case scenario estimated 1,834,583 households (almost 70%) without water on day 1 and 300,422 (> 11%) still without water service after 90 days.

In the best case scenario, 95% of the region's hospitals (196 of 205) were expected to be at least 50% operational on the first day of a modeled earthquake event and no hospital was expected to be completely damaged. The worst case scenario, though, indicated complete damage to 151 of the 205 hospitals in the region (approximately 74%) with the expectation that no hospital would be at least 50% functional on the day of the event.

Although no damage was expected to any of the region's highway segments, highway bridges showed a high potential for damage. Of 21,414 highway bridges in the study region, a minimum of 45 were expected to sustain complete damage, with a high estimate of 4,570 (> 21%) sustaining complete damage in the worst case scenario.

Economic loss estimates included $1.2-46.2 billion in income, $3.5-168.2 billion in capital investments (buildings, improvements and contents), $582 million - $4.7 billion in transportation system infrastructure, and $1.6-13.1 billion in utility system infrastructure for the range of scenarios modeled for this study.

Economic analyses relating to the 7 February 1812 (event ID 4028) scenarios are the most important for the purposes of this study since they relate to the model most likely to adversely impact western Kentucky. Considering only the Global Summary Reports for the two largest scenarios for this historical location (A 4028 81 10/20 and C 4028 81 10/20), the following differences are noted. For the modeled magnitude 8.1

earthquake, 670 to 14,784 deaths are estimated, depending on time of day and modeled attenuation function. Between 14,102 and 182,782 single-family residences are expected to incur complete damage over the entire study region, while between 27,447 and 187,554 more are expected to be extensively damaged and therefore uninhabitable. Potable water is expected to be unavailable for a minimum of 264,959 households, but potentially 1.8 million households on day 1 of the event. Within 90 days of the original event, 4,864 to 229,429 households across the study region are still expected to be without water service. Between 47 and 151 of the region's 205 hospitals are expected to sustain complete damage, with possibly only 2 maintaining greater than 50% functionality on day 1 in the worst-case scenario. Of 21,414 highway bridges, at least 421 are expected to sustain complete damage with a potential 4,368 completely damaged. Monetary losses include $9,641.59-46,234.31 million in income losses, $27,321.49-168,186.94 million in capital investment losses, $179.00-297.90 million in transportation system infrastructure losses, and $5,535.56-13,100.27 million in utility system infrastructure losses. These numbers were not broken down into smaller units within this study, so there is no information on specific impacts to western Kentucky.

4.3 Chinese Design Ground Motion

In acknowledgement of its long history of regional seismicity and earthquake-related casualties, the People's Republic of China has extensive national laws in place to govern and regulate the scientific investigation of seismicity, monitoring of earthquakes, seismic hazard mapping, and emergency response and recovery efforts (MOC PROC, 2001; PROC, 2007; PROC, 2008; etc.). Following the 2008 Wenchuan earthquake, Chinese earthquake mitigation policies were reviewed and modified in response to this event and the data it generated (SC PROC, 2008).

Similarly to the United States, China developed a national seismic hazard map using PSHA for use in mitigation planning. However, China's preferred map is for ground motion with 10% probability of exceedance in 50 years for engineering design and policy considerations (PRCNS, 2001). As shown in Figure 4.8, the design PGAs are quite low, only 0.1 g in the epicentral area of the 2008 Wenchuan earthquake. The highest recorded PGA from the Wenchuan earthquake, however, has been reported as 0.98 g (EERI, 2008). Figure 4.9, modified from Wang et al. (2010), indicates ln(PGA) values in the Wenchuan earthquake epicentral area of greater than 5.5 cm/s^2, corresponding to a PGA of over 0.25 g. This indicates that the design hazard of 0.10 g recommended on the PSHA hazard maps for the Wenchuan area is insufficient for the known potential ground motion.

Seismic design law has mandated building codes based on an assigned seismic fortification intensity (MOC PROC, 2001). A list of intensity assignments for major cities and county areas was included in the building code appendices. In areas of Intensity 6 or above, buildings were to be constructed to seismic standards. The seismic standard was dependent on the use or type of building. In some cases, building to the basic maximum expected acceleration of ground motion for the area was acceptable, but in other cases buildings were to be constructed to withstand one intensity level above the area rating. Table 4.3 outlines the relationships between intensity levels and acceleration of ground motion design requirements. In building code modifications made following the 2008 Wenchuan earthquake, it was noted that buildings generally performed well at one unit of intensity on the Chinese Intensity Scale above their design intensity level (Z. Wang, personal communication, 2014). An increase in acceleration of ground motion design requirement of 0.05 g was instituted for three counties in Gansu Province (Z. Wang, personal communication, 2014) in order to address higher expected ground motions as a result of the effects of and new data gathered from the 2008 Wenchuan earthquake.

In rural areas of China where building materials are scarce, many houses are still built of clay (adobe) or local brick. Due to the natural weakness and friability of unreinforced clays, the seismic building code specified recommendations for building with these materials, giving maximum building heights and room widths (MOC PROC, 2001).

Table 4.1: Hazus Model Ground Motion Minimum and Maximum Values

Model ID	PGA		SA 0.3		SA 1.0	
	Min. Value (g)	Max. Value (g)	Min. Value (g)	Max. Value (g)	Min. Value (g)	Max. Value (g)
A 4026 72 10/20	0.00740	2.308	0.02942	3.914	0.03759	4.222
C 4026 72 10/20	0.00848	1.517	0.01908	2.102	0.02209	1.739
A 4026 77 00/10/20	0.01046	2.809	0.04013	4.649	0.05325	5.150
C 4026 77 00/10/20	0.01328	1.854	0.02891	2.648	0.03411	2.268
SW Fault 1	0.02000	1.100	0.02000	1.380	0.02000	1.140
A 4026 82 10/20	0.01426	3.308	0.05199	5.263	0.06988	5.839
C 4026 82 10/20	0.01958	2.253	0.04081	3.160	0.04770	2.701
A 4027 71 10/20	0.02153	2.210	0.08601	3.760	0.10870	4.022
C 4027 71 10/20	0.01433	1.447	0.03794	1.983	0.04311	1.628
A 4027 75 10/20	0.02860	2.607	0.11150	4.365	0.14620	4.799
C 4027 75 10/20	0.02012	1.700	0.05193	2.423	0.06088	2.043
A 4027 79 10/20	0.03713	3.011	0.13990	4.914	0.18710	5.463
C 4027 79 10/20	0.02811	1.992	0.06947	2.843	0.08099	2.458
A 4028 74 10/20	0.03533	2.506	0.13880	4.217	0.18050	4.612
C 4028 74 10/20	0.02192	1.657	0.05911	2.340	0.06920	1.959
A 4028 78 10/20	0.04619	2.910	0.17570	4.785	0.23420	5.312
C 4028 78 10/20	0.03056	1.943	0.07909	2.773	0.09295	2.384
A 4028 81 10/20	0.05564	3.210	0.20530	5.154	0.27190	5.728
C 4028 81 10/20	0.03776	2.185	0.09483	3.086	0.11130	2.651

Models highlighted in light gray indicate the point-source hazard models and fault line model which correlate for general location, depth, and earthquake magnitude. Differences include the attenuation function and fault line rather than point hazard source. Models highlighted in light pink indicate the most important scenarios for western Kentucky.

Table 4.2: Analysis Summary for Selected Scenarios. Various statistical estimates from the Global Summary Reports of selected Hazus scenarios. Figures apply to the entire study region and have not been specified for smaller areas within the study region.

Model ID	PGA Range (g)	SA 1.0 Range (g)	Fatalities (range)	Income and Capital Stock Losses (in millions of dollars)	Transportation and Utility System Losses (in millions of dollars)
A 4028 74 10/20	0.04 - 2.51	0.18 - 4.61	1,282 - 3,061	67,737.93	9,863.75
C 4028 74 10/20	0.02 - 1.66	0.07 - 1.96	109 - 244	7,208.23	3,503.92
A 4028 78 10/20	0.05 - 2.91	0.23 - 5.31	6,483 - 12,002	175,537.60	14,141.99
C 4028 78 10/20	0.03 - 1.94	0.09 - 2.38	403 - 862	24,406.58	5,492.91
A 4028 81 10/20	0.06 – 3.21	0.27 - 5.73	8,114 - 14,784	214,421.25	17,809.27
C 4028 81 10/20	0.04 - 2.19	0.11 - 2.65	670 - 1,482	36,963.08	7,219.36
A 4026 77 10/20	0.01 - 2.81	0.05 - 5.15	5,220 - 9,892	140,971.33	11,951.64
C 4026 77 10/20	0.01 - 1.85	0.03 - 2.27	364 - 840	23,309.79	4,623.73
SW Fault 1	0.02 - 1.10	0.02 - 1.14	720 - 1,176	34,194.85	9,203.49

Table 4.3: Chinese Design Requirement Relationships. Relationships between expected seismic intensity and acceleration of ground motion design requirements from the national seismic design code of the People's Republic of China (MOC PROC, 2001).

Seismic Fortification Intensity	**6**	**7**	**8**	**9**
Acceleration of Ground Motion Design Requirement	0.05 g	0.10 or 0.15 g	0.20 or 0.30 g	0.40 g

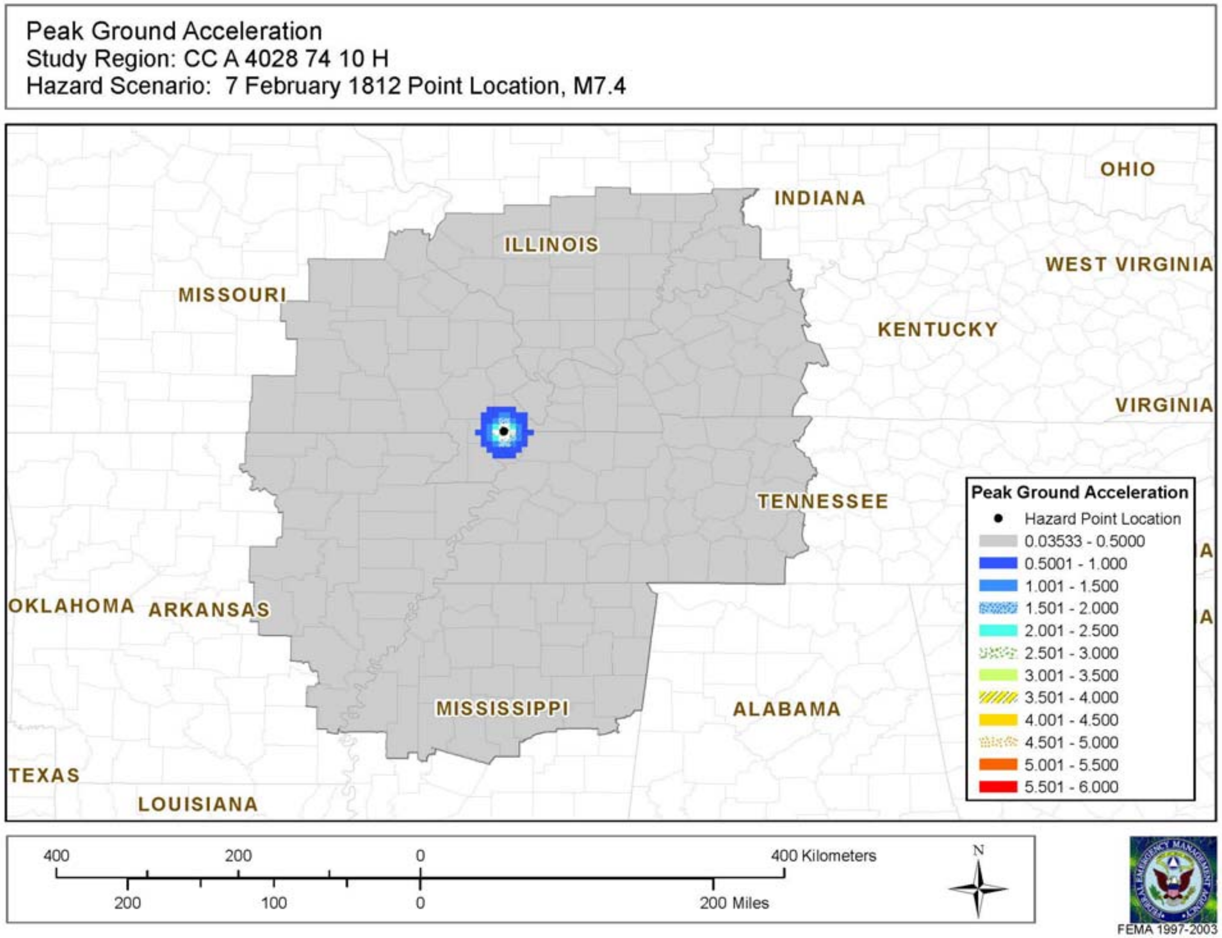


Figure 4.1: Peak Ground Acceleration Contour Map for A 4028 74 10. A smaller earthquake magnitude for any location and attenuation function returned lower ground motion values and contours than larger magnitude events at the same location and attenuation function, as expected. For comparison, see Figure 4.2, Peak Ground Acceleration Contour Map for A 4028 81 10, a magnitude 8.1 event at the same location and using the same attenuation function.

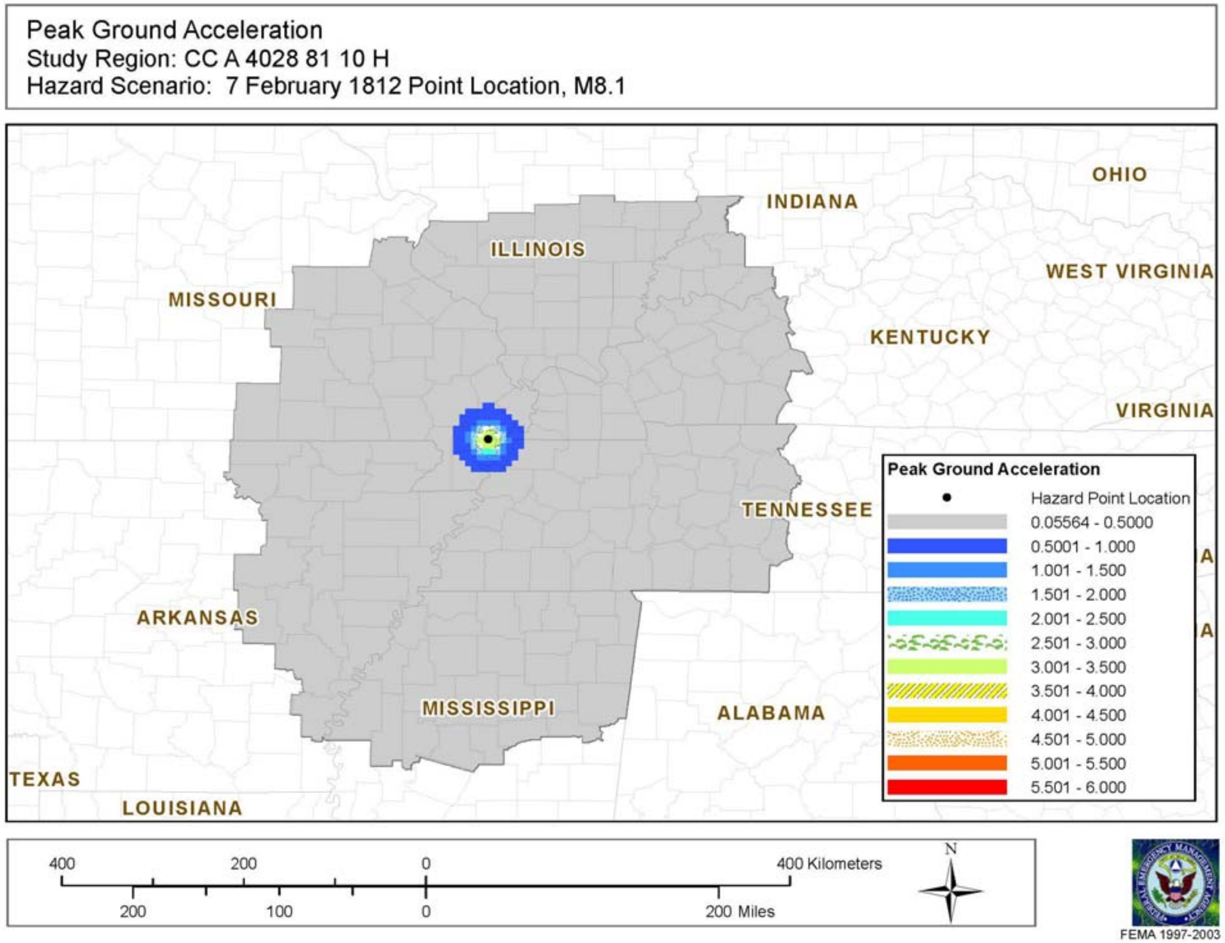


Figure 4.2: Peak Ground Acceleration Contour Map for A 4028 81 10. A larger earthquake magnitude for any location and attenuation function returned higher ground motion values and contours than smaller magnitude events at the same location and attenuation function, as expected. For comparison, see Figure 4.1, Peak Ground Acceleration Contour Map for A 4028 74 10, a magnitude 7.4 event at the same location and using the same attenuation function.

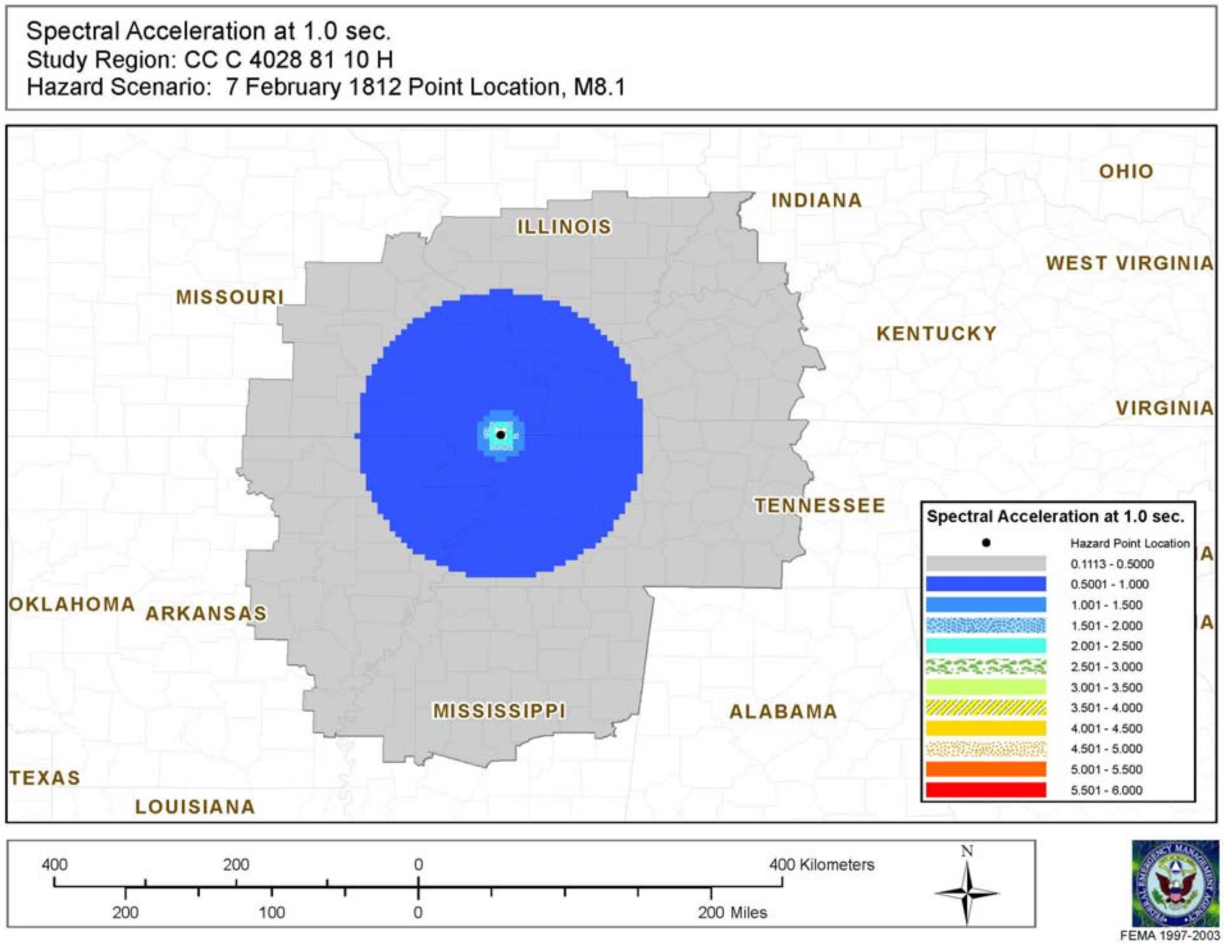


Figure 4.3: Spectral Acceleration at 1.0 sec. Contour Map for C 4028 81 10. Scenarios using the composite attenuation function, C 2008, consistently returned lower ground motion values and smaller contours than models at the same locations and magnitudes using the A&B 2006 attenuation function. See Figure 4.4, Spectral Acceleration at 1.0 sec. Contour Map for A 4028 81 10, for comparison.

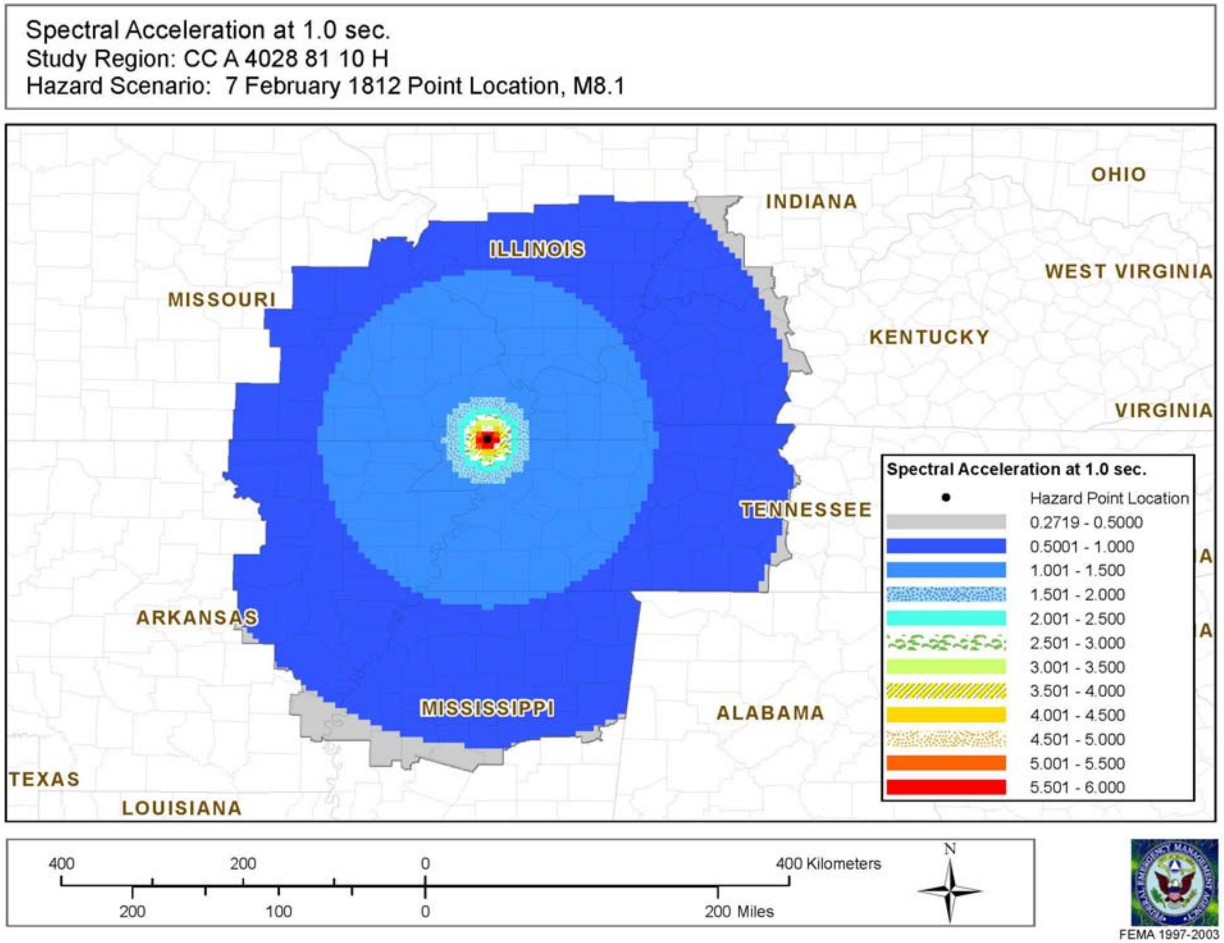


Figure 4.4: Spectral Acceleration at 1.0 sec. Contour Map for A 4028 81 10. Scenarios using the A&B 2006 attenuation function consistently returned higher ground motion values and larger contours than models at the same locations and magnitudes using the composite attenuation function, C 2008. See Figure 4.3, Spectral Acceleration at 1.0 sec. Contour Map for C 4028 81 10, for comparison.

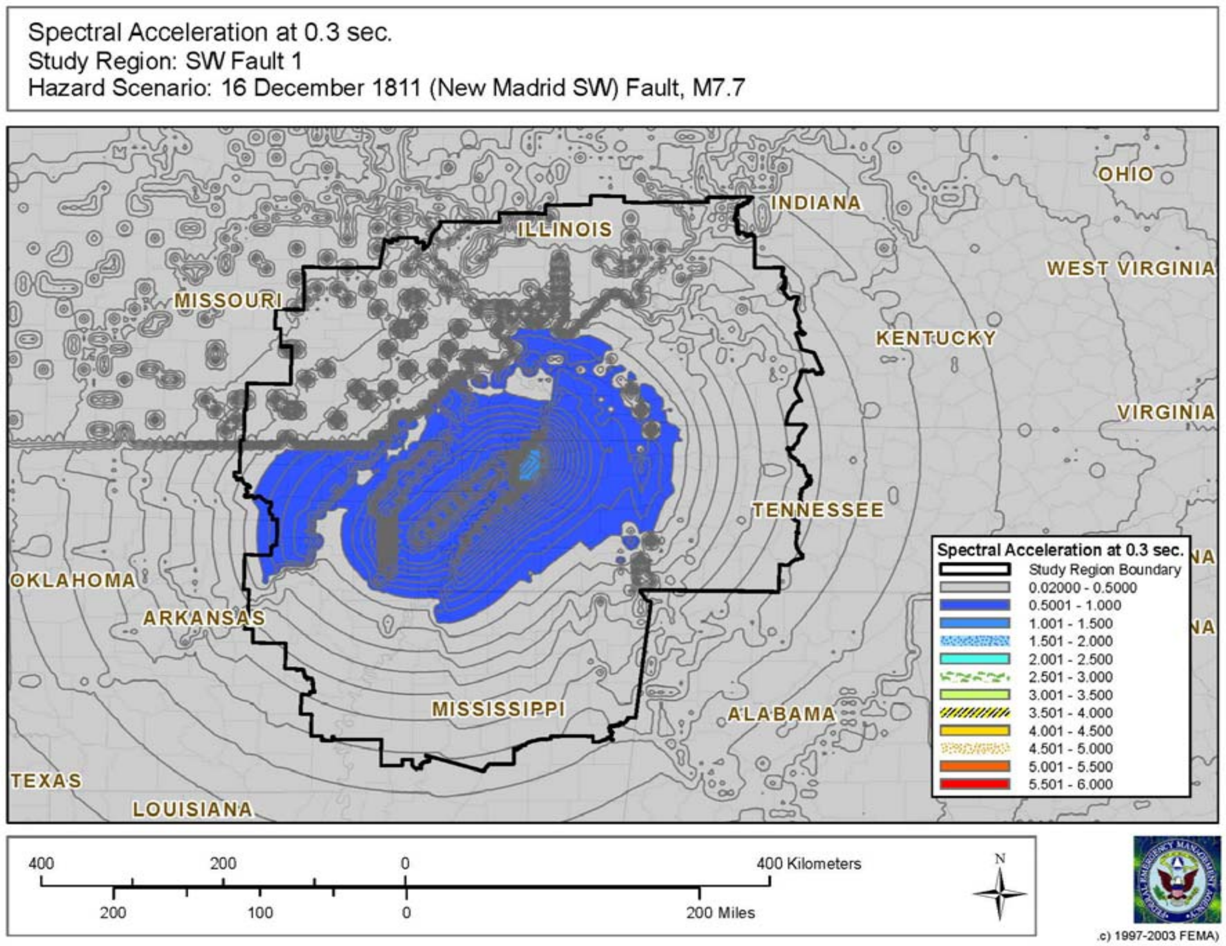


Figure 4.5: Spectral Acceleration at 0.3 sec. Contour Map for SW Fault 1. Fault line scenario ground motion values and contours differed from point-source scenarios at the same location and depth based on both line vs. point geometry and attenuation function effects. Compare to Figures 4.6, Spectral Acceleration at 0.3 sec. Contour Map for C 4026 77 10, and 4.7, Spectral Acceleration at 0.3 sec. Contour Map for A 4026 77 10. Contour maps for other ground motion variables are included in Appendix D.

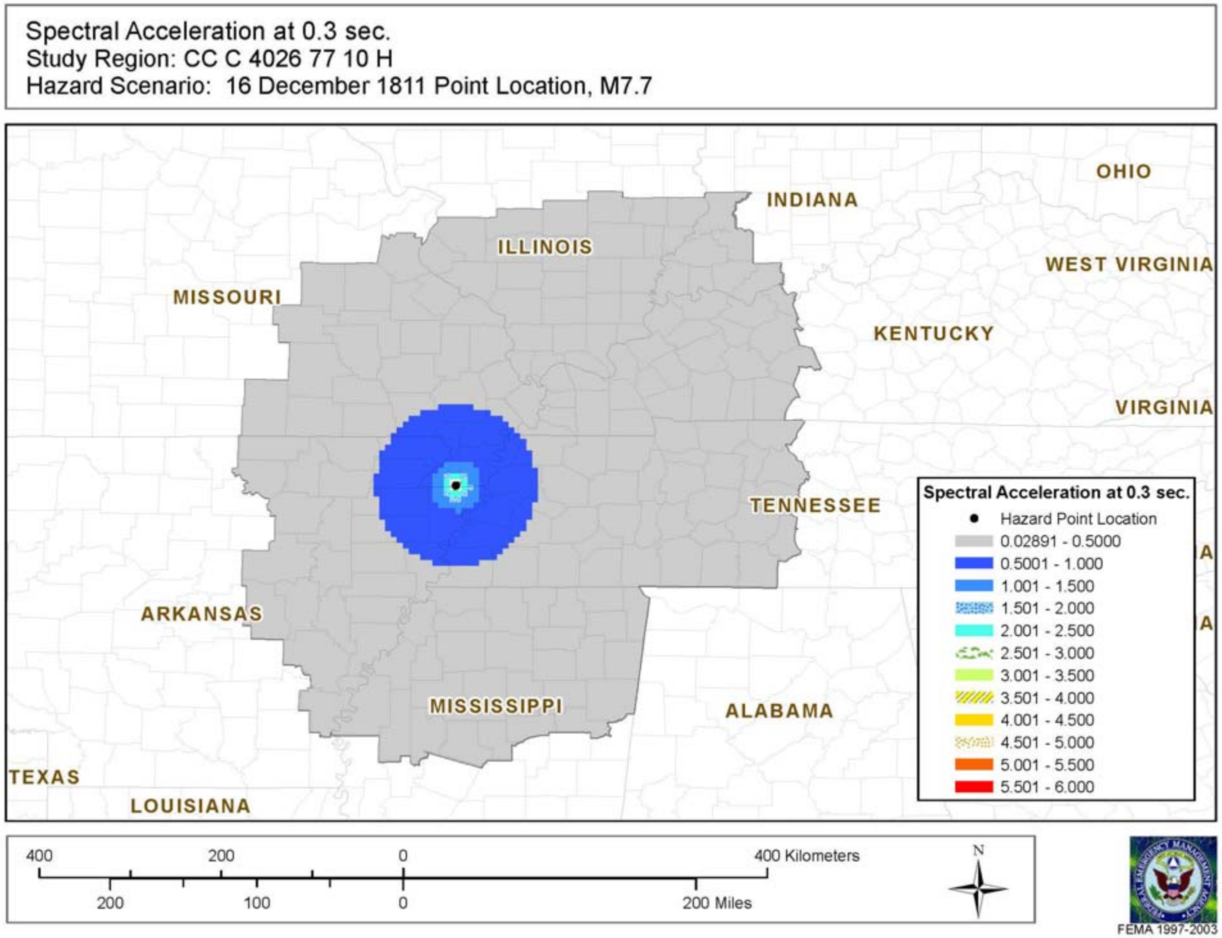


Figure 4.6: Spectral Acceleration at 0.3 sec. Contour Map for C 4026 77 10. Fault line scenario ground motion values and contours differed from point-source scenarios at the same location and depth based on both line vs. point geometry and attenuation function effects. Compare to Figures 4.5, Spectral Acceleration at 0.3 sec. Contour Map for SW Fault 1, and 4.7, Spectral Acceleration at 0.3 sec. Contour Map for A 4026 77 10. Contour maps for other ground motion variables are included in Appendix D.

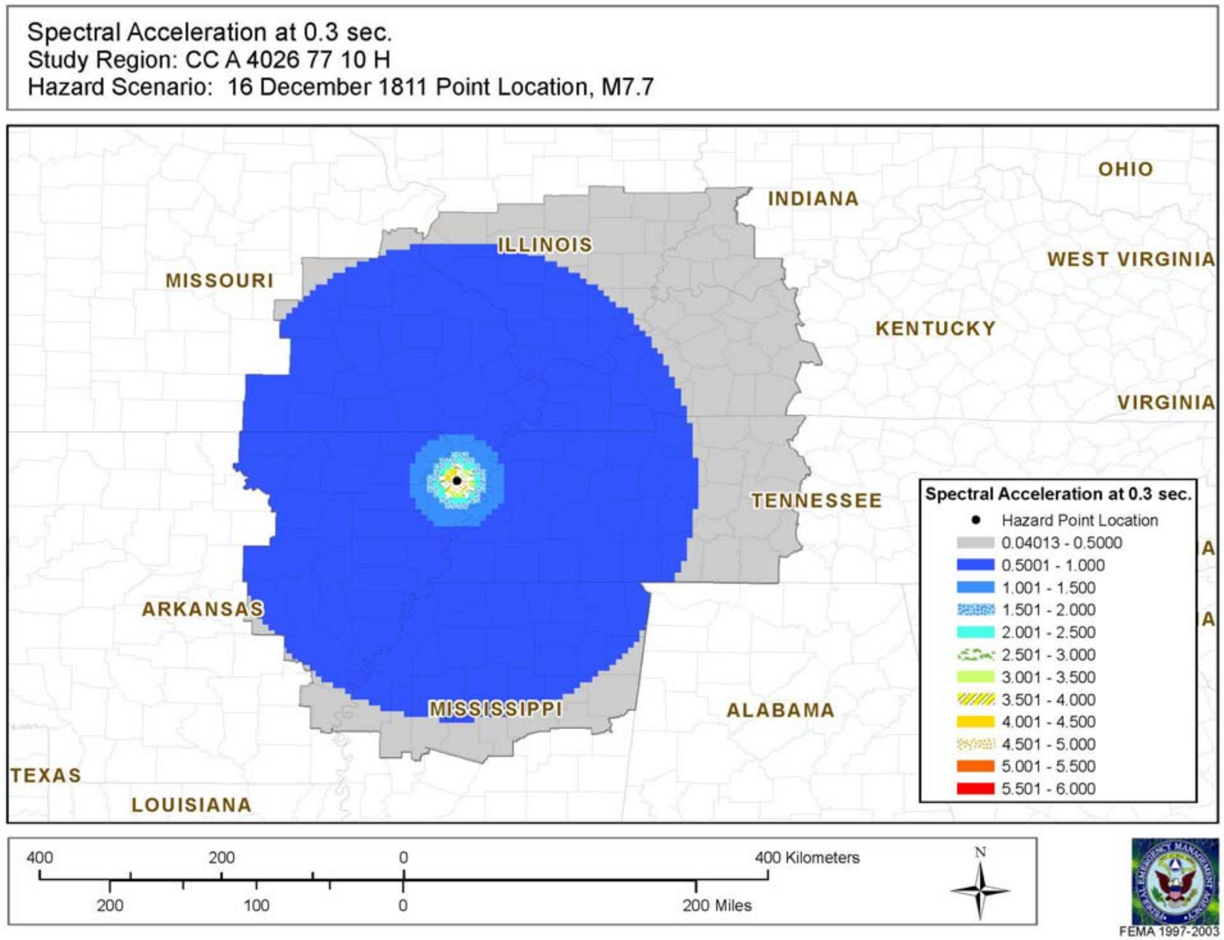


Figure 4.7: Spectral Acceleration at 0.3 sec. Contour Map for A 4026 77 10. Fault line scenario ground motion values and contours differed from point-source scenarios at the same location and depth based on both line vs. point geometry and attenuation function effects. Compare to Figures 4.5, Spectral Acceleration at 0.3 sec. Contour Map for SW Fault 1, and 4.6, Spectral Acceleration at 0.3 sec. Contour Map for C 4026 77 10. Contour maps for other ground motion variables are included in Appendix D.

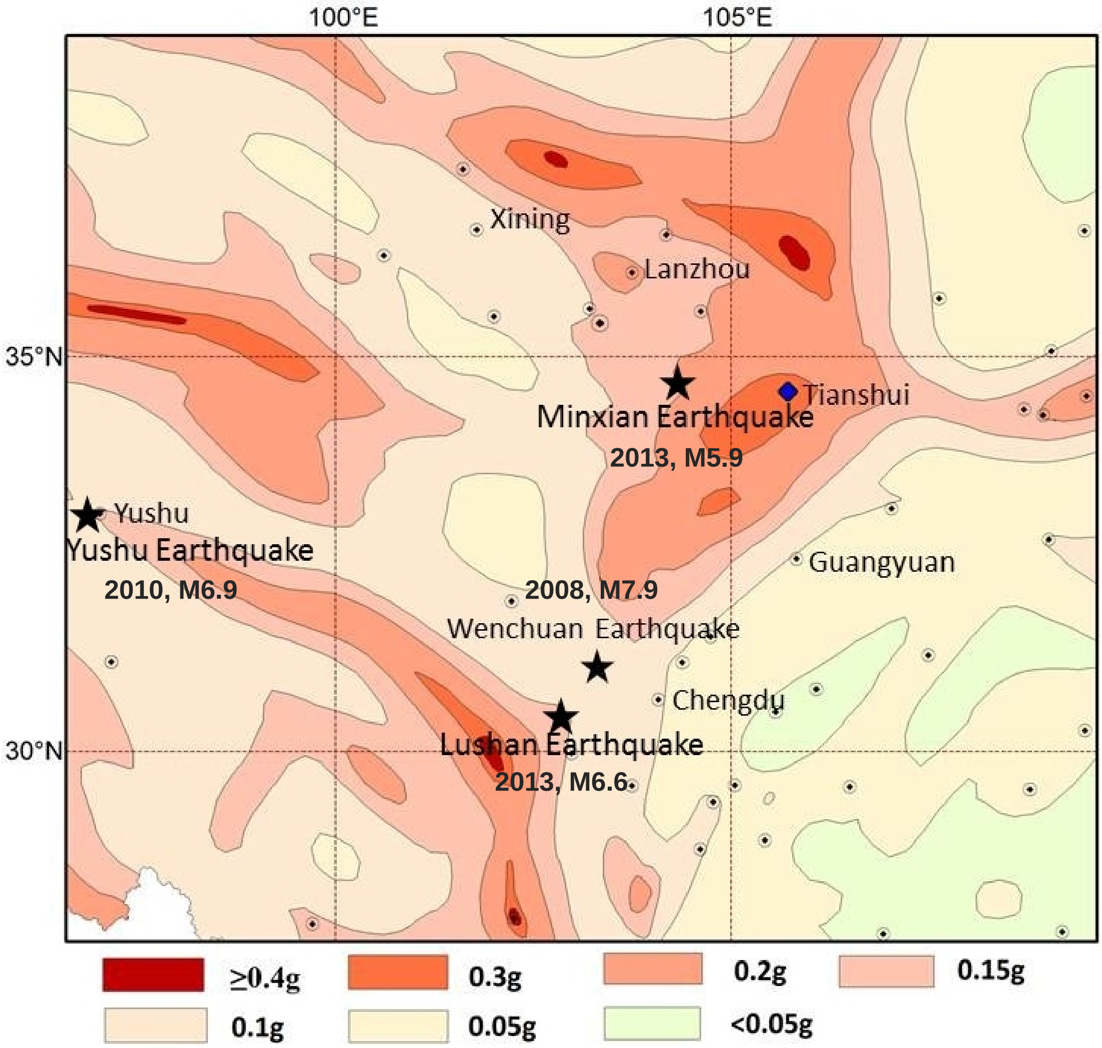


Figure 4.8: Chinese National Seismic Hazard Map. Chinese national seismic hazard map for the Wenchuan earthquake affected area showing design peak ground acceleration (PGA). Stars indicate approximate locations of recent earthquakes. (Modified from PRCNS, 2001.)

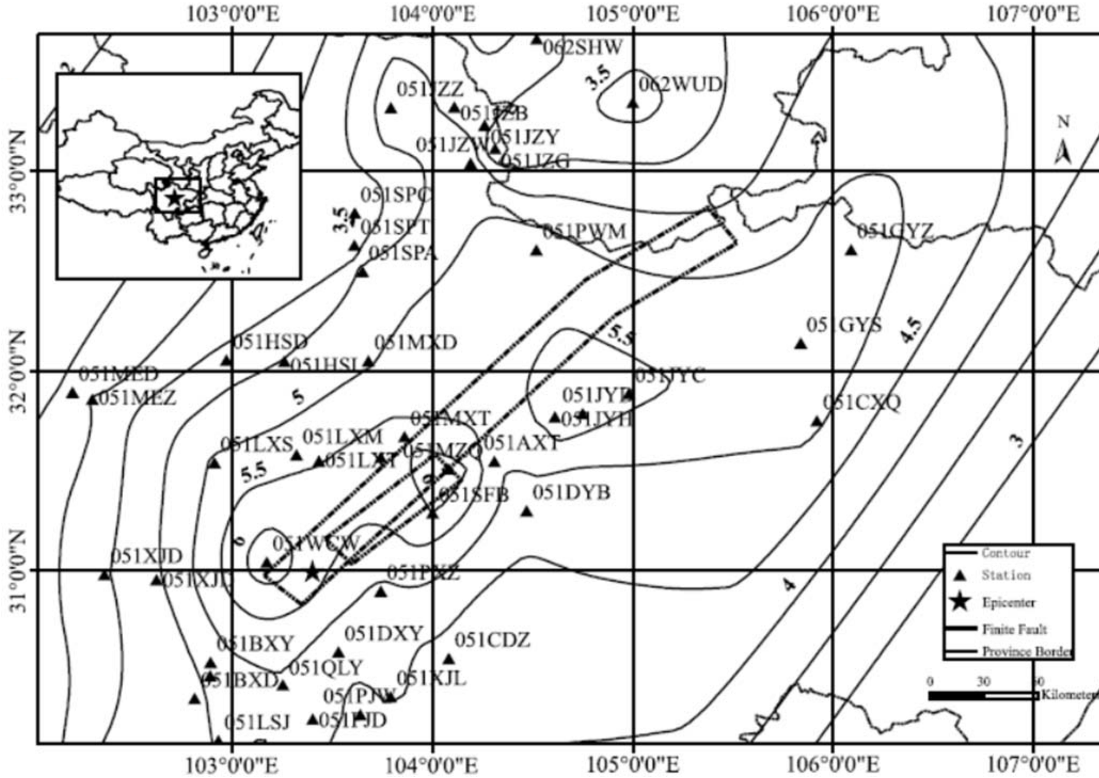


Figure 4.9: 2008 Wenchuan Earthquake ln(PGA) Contours. Contour map of the natural log of peak ground acceleration (ln(PGA) values) for the epicentral area of the 2008 Wenchuan earthquake in units of cm/s^2. High values of over 5.5 on this map correspond to approximately 0.25 g PGA values. (Modified from Wang et al., 2010.)

CHAPTER 5: DISCUSSION AND CONCLUSIONS

5.1 Interviews

Interviews were conducted for the purpose of establishing the range of general knowledge of science and engineering practice in the NMSZ as well as to identify local concerns in western Kentucky regarding the impacts of current science practice on public policy and the economy. These interviews were intentionally informal and variable in order to create an open forum for participants to express views about the topics of interest that could not be adequately addressed with a formal yes/no questionnaire, but also hopefully without leading the interviewees to pre-determined opinions or conclusions. Because all questions were not asked during all interviews, or some questions were asked but not answered, and because not all survey populations were evenly represented among the respondents, the interview responses may not serve as a complete view of the issues. However, enough information was gathered to begin building a framework for addressing the concerns of this research.

During the course of these interviews it became clear that while the concern for earthquake risk mitigation and safety of people was quite important, it was not the only issue of concern to western Kentucky businessmen, professionals and public officials. There was also great concern that the regional earthquake hazard had been either over- or understated in a given area, and that there were both safety and economic costs associated with the discrepancy. There was some sense from engineering and real estate development professionals that the methods used for creating the NSHM series do not return realistic results because of the amount of uncertainty in the underlying science. Although the NSHM were known, they were rarely understood and not often perceived as the authoritative, trusted source for information regarding earthquake hazard potential.

On the federal level, there seemed to be little understanding of the impact that the scientific uncertainty has at local levels, although federal employees were admittedly underrepresented and interview results are not suggested to represent the position of the entire federal government. However, current map science and methods have been published by the federal government, and individuals and communities may use the information at their own discretion. Additionally, some tools for earthquake hazard education and analysis and building design information have been developed by various federal agencies and are outlined in publications as well as available online for general use (USGS, 2008f). Examples include the National Seismic Hazard Map series, earthquake data, shake maps, scenario models, modeling software packages, earthquake probability mapping tools, a worldwide seismic design values calculation tool, and others. However, it is clear from interview results that not enough of this information is making its way to the end users to allow them to have confidence in the science. When it has been clearly stated that the purpose of the NSHM series is to inform seismic design provisions for building codes and insurance rates (USGS, 2008f), some responsibility should be taken to ensure that the information and data are used appropriately and that limits of knowledge are communicated. Although it may or may not be true that the current NSHM series represents the best current science, additional education of engineering professionals and public emergency management and education personnel would clarify the scientific process, current practices, and uncertainty so that appropriate public policy, building codes, education, and planning can take place.

A second policy concern is that federal agencies apply different standards, codes or rules than local and state agencies do. The effect is two-fold. First, this double standard may allow the federal government to outsource jobs to out-of-area contractors or labor forces making these jobs unavailable to local workers. Several interviewees referenced the idea that the U.S. Army Corp of Engineers applies its own standards, not local building codes, and provides its own workforce. This action is perceived as both an unfair advantage for project approval ("you can build something we are not allowed to build due to local regulations") and a removal of local jobs to outside labor pools (labor is performed by non-local government employees or contractors). The second effect of different standards for federal agencies is in the case of higher seismic standards causing higher project costs, effectively pricing federal projects out of the region. The most well-known example of this is the higher standards required by the Nuclear Regulatory Agency for the Paducah Gaseous Diffusion Plant and the associated proposed but rejected uranium enrichment centrifuge facility. Denial of this project for development at the existing nuclear facility is seen as a direct result of the NSHM estimates of high seismic hazard in the Paducah area. Local perception is that the costs of building a plant to federal standards in the current location are so much higher than the costs of building elsewhere that the project is not feasible in western Kentucky. The difference between local and federal policies is therefore credited with the direct loss of over 1,200 local jobs and the indirect loss of thousands more jobs in support industries and community services.

5.2 Hazus Analyses

The 38 point-source hazard scenarios were developed based on best-estimates of historical locations, magnitudes and intensities of great earthquakes in the New Madrid Seismic Zone. As such, these scenarios do not have associated probabilities of occurrence but are strictly scenario event hazards and are not directly comparable to the probabilistic NSHM. They are, in fact, specific cases of the potential probabilistic earthquakes for the region and cover only the very high range of maximum credible earthquake events. As such, the ground motion contour maps and economic analyses returned by Hazus are expected to be worst-case scenarios as compared with the NSHM for the NMSZ with 2% probability of exceedance in 50 years. The single fault line hazard model is also a scenario model for a specific event, and therefore not directly comparable to the NSHM. However, data for the fault line scenario were developed by the USGS earthquake hazards team and are considered to be the federally accepted probable historical event for the 16 December 1811 earthquake based on current information, and as such are also an extreme event scenario.

Since the magnitude and depth variables for the fault line scenario correlate exactly with the mid-range estimates of the same variables culled from the literature review, the fault line model is somewhat comparable to the point-source hazard models for the same location and magnitude. Remaining variables are the differences between point and line source areas and differences between attenuation function estimates of ground motion, but the differences in these variables cause marked differences in scenario outputs. As the most extreme examples, the SA 1.0 maximum value for Model A 4026 77 10 is 4 g greater than the SA 1.0 maximum value for SW Fault 1. The affected ground motion areas are much larger for PGA for the SW Fault 1 model than for either point hazard model, while they are similar to the CEUS 2008 contours (allowing for additional length for the fault component) for SA 0.3 and SA 1.0 areas.

For purposes of this study, the most important scenarios were those related to the historical 7 February 1812 earthquake location (model IDs using the 4028 location identifier). This location was both considerably closer to western Kentucky than the other large earthquakes in the 1811-1812 New Madrid series as well as the largest of the historical earthquake series (Hough et al., 2000). However there was no fault scenario readily available at this location for comparison to the Hazus point-source scenarios so a rough comparison has been made to the SW Fault 1 and 16 December 1811 point-source earthquake scenarios (model IDs using 4026 location identifier) which occurred to the southwest. Model IDs A 4026 82 10, C 4026 82 10, A 4028 81 10, and C 4028 81 10 were considered along with the fault scenario (Model ID SW Fault 1) and associated point-source scenarios for the same location and magnitude (model IDs A 4026 77 10 and C 4026 77 10).

All PGA contours for point-source models returned smaller affected areas than the SW Fault 1 model, both in area length due to the point vs. fault nature of the comparison as well as in diameter of affected area. SA 0.3 contours for C 4028 81 10 and C 4026 82 10 were similar in diameter to the SW Fault 1 scenario, while A 4028 81 10 and A 4026 82 10 SA 0.3 contours and all SA 1.0 contours were much larger than their counterpart contours in the SW Fault 1 scenario. Additionally, all contours for point-source models showed a much more extensive range of values than the fault scenario. A 4028 81 10 ground motion contours were similar in extent to their A 4026 82 10 counterparts, and C 4028 81 10 contours were similar to C 4026 82 10 contours, although shifted appropriately to the northeast to account for the change in epicentral location in that direction. Please refer to Table 5.1, Scenario and NSHM Ground Motion Values, for actual data values.

The NSHM, by comparison, are PSHA models, meaning that they are not specific events but are a probability indicator that a certain type of event will occur within a certain timeframe. The values given on the NSHM are always associated with a probability of occurrence and timeframe. As such, they are not directly comparable to the scenario models and analyses developed within Hazus. However, if we have chosen scenario events to model that are agreed to have a likelihood of occurrence, then each of the Hazus models should fall within the scope of a NSHM. That is, each of the scenario models developed and analyzed with Hazus should be a contributing event for the NSHM series, which is an overarching compilation of likely events. Because the variables for the Hazus models were chosen specifically to meet the criteria of likely events for the NMSZ by using historical locations, depths and magnitudes, and by specifying widely accepted attenuation functions, the Hazus models should be a specific subset of events included within the scope of the NSHM. In fact, they should comprise the extreme high end of potential earthquake events considered within the NSHM probabilities. With this perspective in mind, we can compare the Hazus ground motion maps to those derived for the NSHM.

Ground motion data from the 2008 NSHM Gridded Data files were downloaded for the NSHM with 2% probability of exceedance in 50 years (USGS, 2012b). These data were edited to retain only data points and associated ground motions within the approximate study region of NMSZ central counties used for the Hazus models (84° W – 92° W, and 33° N – 39° N) and a comparison was made between high and low ground motion values used for the NSHM and those generated for the Hazus models. The PGA minimum value for the NSHM (~0.06 g) is the highest of the PGA minimums, making it the worst-case scenario for minimum PGA. The NSHM PGA maximum, however, at just under 2 g (~1.98 g) is a lower value than 2/3 of the Hazus models, meaning that the NSHM indicates a more conservative expectation, a better scenario, than 2/3 of the Hazus models. The comparison for SA 0.3 values is similar, with the NSHM model on the high end of the minimum values (at ~0.14 g) and close to the mean of the high SA 0.3 values (at ~3.57 g), with half the Hazus models returning higher and half returning lower maximum SA 0.3 values. The SA 1.0 value comparisons are slightly different, with the NSHM minimum in the mid-range but lower than the mean value at ~0.07 g, but the NSHM maximum value lower than all but the fault line model (~1.3 g). This last makes it almost the best case scenario for maximum SA 1.0 value.

Overall, the NSHM 2% PE in 50 years illustrates a conservative range of ground motion values when compared to the Hazus models. This is reasonable considering that the Hazus scenarios were developed to cover the worst case historical earthquakes. If anything, the surprise is that the NSHM values are within the range of the worst-case values. Considering the complete range of likely earthquakes and the very infrequent recurrence of these high-magnitude events, we should really expect that the NSHM high ground motion values would be considerably below the selected scenario events. This discrepancy again highlights the range of uncertainty dependent on model parameters and assumed versus proven local or regional conditions.

The 2008 NSHM contoured map values are slightly different than the downloaded data values would indicate. Whereas the maps indicate high PGA and SA 1.0 values of 1.2 g and a high SA 0.3 value of 3.0 g, the available data give PGA maximum of 1.98 g, SA 0.3 max. of 3.57 g, and SA 1.0 max. of 1.3 g. These variations may be due to changes made to the maps since the original 2008 map release as discussed in documentation for Revision II and Revision III (USGS, 2012c). The ground motion values for the NSHM series have varied over time as more information and data have been collected and as attenuation function models have been developed and refined. In addition to revisions to the 2008 map versions, the 1996 NSHM for the central and eastern U.S. for PGA with 2% PE in 50 years indicated a high for the NMSZ of between 1.2 and 1.6 g, while the 2002 version indicates a high between 1.6 and 2.0 g, and in the 2008 version a high of 1.2-1.98 g was indicated over the various revisions. The overall effect seems to be a yo-yo effect as different models are considered and new inputs are collected and evaluated. Overall the maps indicate a small decrease in PGA by the last revision (in 2010), but very slight. Recent GPS data indicating negligible regional strain accumulation for the NMSZ (Calais and Stein, 2009; Stein, 2014) may help to revise the general model of steady-state behavior. As more data are collected estimates of seismic hazard may be modified to continue the decrease of ground motion expectations. A selection of maps from the NSHM series has been included in Appendix F for reference.

From an historical perspective, the 1811-1812 large earthquakes were originally believed to fall within the Intensity VII to IX range on the Modified Mercalli Intensity scale in the western Kentucky area (Nuttli, 1973). However, because the scale is subjective this range has since been investigated and modified to account for factors such as scarcity of data, proximity of witnesses to highly sedimented riverine areas, expectation of a smooth contour line, and newer mathematical modelling tools (Johnston, 1996; Hough et al., 2000). These more recent intensity estimates lower the range slightly to Intensities VI to VIII+. For comparison, the USGS ShakeMap for the New Madrid SW M7.7 Scenario also indicates Instrumental Intensity estimates for western Kentucky of VI to VIII (USGS, 2011). These intensities correlate to PGA values between 0.09 g and 0.65 g, which are also returned for the PGA values in western Kentucky for each Hazus 7 February 1812 scenario (model IDs with 4028 event identifier). Contrarily, the 2008

NSHM (2% PE in 50 yrs.) data indicate a PGA range of 0.20 g to about 1.85 g for this same region, a substantial increase over historical estimates.

While the Hazus models returned a highest PGA value of greater than 3.3 g for the models run (see Table 5.1), it should be mentioned that these values are extreme and unrealistic. NSHM PGA values exceeding 1.2 g in the NMSZ are similarly unlikely. For comparison, the actual high PGA value for the magnitude 7.9 Wenchuan earthquake was 0.98 g. Because some of the Hazus scenarios are of greater magnitude than the Wenchuan event, some PGA values larger than the Wenchuan high value might be expected for larger scenario event models. But the composite nature of the NSHM series should indicate lower PGA values than the real data for these high magnitude events as the PSHA functions smooth the highs with many more low magnitude events and PGA values. This discrepancy again indicates the uncertainty associated with modeling. Ultimately, models will need to be iteratively revised with consideration for real data to be reliable for hazard mapping.

The stated purpose of the Hazus Earthquake Model software is "to produce loss estimates for use by federal, state, regional and local governments in planning for earthquake risk mitigation, emergency preparedness, response and recovery" (FEMA, 2012c). However, software documentation also indicates that "uncertainties are inherent in any loss estimation methodology," and that the range of uncertainty within the Hazus Earthquake Model is "possibly *at best* a factor of two or more." Factors include incomplete default built environment assessments or inventories, changes in demographic databases, and changing economic parameters. Note that these economic factor uncertainties are in addition to the underlying scientific uncertainties involved in generating ground motion contour maps discussed above. Using only default Hazus databases, a single soil condition is assumed for all analyses although local geology may vary widely. It is also acknowledged that the attenuation functions tend to be conservative for both scenario and probabilistic ground motion estimates. For estimates with lower uncertainties, additional information about the study region would need to be input to the associated databases. More accurate data will return more accurate results. Data regarding local soil conditions and specific locations of source faults would be required to minimize the ground motion uncertainties, while specific physical inventory and demographic information would better constrain the economic and other damage estimates.

In addition to future impacts, ongoing economic impacts of mitigation requirements can also be assessed via cost analysis studies. A long-awaited cost analysis was recently released regarding earthquake-resistant construction in the Memphis, Tennessee area (NEHRP CJV, 2013). The report concludes that building construction costs to meet current national seismic resistance standards are approximately 3% or less, and 1% or less to meet current design standards for the Memphis area compared with requirements to design strictly for wind loads without consideration of seismic resistance. Western Tennessee and western Kentucky are in the same wind zone (Zone IV; FEMA, 2012d) and similar seismic ground motion zones (USGS, 2012a), as well as being within a similar region of the central United States, so many of the cost analysis principles can be assumed to be correct for the western Kentucky area. However, these costs are very different from the information gleaned from interviews with design and building professionals in western Kentucky which indicated 1-20% cost increases due to seismic mitigation requirements. On closer examination, the report models costs for construction only and does not address indirect building costs such as associated design fees for seismic requirements, additional time required to address permit and inspection requirements, or earthquake insurance over the life of a building's mortgage. This difference is likely to account for the extreme difference in mitigation requirement cost estimates between the report and anecdotal accounts. It is suggested that a true cost analysis considering these and other indirect costs of meeting seismic mitigation requirements be done to complement the recent construction cost benefit analysis.

5.3 China Policy Implications

When it comes to seismic design for building, China has a nationally mandated plan in place. It differentiates for regions of higher seismic hazard based on locations of faults and frequency of recurrence of earthquakes, as well as for types of building uses and occupancy levels. Critical structures such as hospitals and schools are to be built to higher design standards than single-residence structures or non-occupancy structures. Some leeway is given for rural areas where building materials may be limited or where cultural traditions are strong, but whenever possible a better or higher standard than the minimum is encouraged. Within the Sichuan Province, the epicentral area for the 2008 Wenchuan earthquake, the seismic fortification intensity assignment for most cities is Degree 7 with design basic ground motion of 0.10 or 0.20 g, but as high as Degree 8, design basic ground motion 0.30 g for a few areas and Degree 9, design basic acceleration of 0.40 g for two areas (MOC PROC, 2001). The design basic ground motions correlate to U.S. PGA values (Z. Wang, personal communication, 2014).

Within the United States, construction projects that fall outside the jurisdiction of federal agencies are governed by the policies of states or by local agencies under the umbrella of state mandates. Although most of the states have adopted some version of the International Building Code (IBC), requirements and exceptions vary. Within the Commonwealth of Kentucky, general building requirements are mandated statewide under the Kentucky Building Code, based on the IBC. Residential building requirements are established under a separate document, the Kentucky Residential Code, for construction of detached single-family or two-family dwellings and townhouses (KBHBC, 2013).

Similarly to China's seismic design requirements, Kentucky's building code establishes basic seismic acceleration design parameters for each county. These requirements are intended to be minimums, but may be improved by calculations for a specific building site. Seismic design requirements in Kentucky may also be increased for building use or occupancy expectations as they are in China.

Following the 2008 Wenchuan earthquake, with approximately 90,000 people either confirmed dead or missing, the evaluation of performance of buildings relative to shaking was of primary concern. An estimated 5.36 million buildings completely collapsed, while more than 21 million more were damaged (USGS, 2008b). The failure of school buildings and hospitals within the impacted region was widely acknowledged (EERI, 2008; Paterson et al., 2008; Miyamoto et al., 2009). One report indicated that as many as 100 schools had collapsed, killing at least 10,000 children (Paterson et al., 2008). Some of these buildings were older and did not conform to current seismic standards (EERI, 2008), but others were constructed in the 1980s and 1990s when seismic construction requirements were in place; however, the additional seismic construction requirements were still inadequate for this large event (Miyamoto et al., 2009). At the same time, the ability of other seismically improved buildings to withstand collapse was also widely acknowledged (Free et al., 2008; Miyamoto et al., 2009). One factor contributing to the failure of structures was that the ground shaking was both much larger and much longer than anticipated (Free et al., 2008). It simply exceeded the level of seismic protection that was required for construction, so even buildings constructed to code were not strong enough. Having acknowledged this deficiency, it becomes clear that China's design map is not adequate for this seismically active area.

As stated previously, the Chinese national seismic hazard maps were produced using PSHA methodology. Although PSHA is the most widely used method for seismic hazard assessment, it has been found that PSHA is a purely numerical or computer model without physical and mathematical basis, and its results are artifacts of the math (Wang, 2011; Wang and Cobb, 2012). Unreliable underlying scientific principles may translate into either overly conservative or unsafe mitigation policies when PSHA-based hazard maps are used for mitigation applications. Earthquake science is the fundamental element for developing sound seismic hazard mitigation policies. While poor science will lead to problematic mitigation policies, creating understandable, scientifically defensible hazard maps will allow for adequate earthquake preparation. Communities will neither be left chasing disasters, having prepared for too low a hazard level, nor over-building for unnecessarily high hazard levels. This will be better done through use of deterministic seismic hazard analysis for seismic hazard map development.

In the Wenchuan earthquake, the buildings that suffered the most damage were either not built to code requirements (either predating requirements or of shoddy construction) or were in areas where the earthquake ground motion effect was much larger than code requirements anticipated. Prior to this time, implementation of building codes varied greatly and enforcement at local levels was sometimes problematic, particularly during economic boom periods. However, buildings constructed to an Intensity 7 level of seismic mitigation, even if not to the full Intensity 9 level occasionally required, remained standing and lives were saved by this preparation. Buildings built to at least Intensity 7 level, although suffering some damages, were repairable.

Additionally, before the Wenchuan earthquake, the Chinese government launched a campaign to promote seismic resistant homes for farmers in rural areas by giving government assistance in the form of subsidies (Wang et al., 2005). Many new homes were built in southeastern Gansu Province through this campaign. As illustrated in Figure 5.1, the seismic resistant houses suffered little or no damage during the 2008 Wenchuan earthquake, while traditional unreinforced adobe houses suffered severe or complete damage. In central China, communities that built a seismic hazard-resistant environment through appropriate code requirements coupled with adequate enforcement and use of government assistance programs for particularly at-risk sectors sustained minimal impacts. Within the central United States, building to life safety levels rather than no-damage risk-targeted levels can also provide desired safety conditions while easing economic impacts to communities.

5.4 Uncertainty Implications

We have a much higher population in the central United States than existed when the last large earthquakes occurred in the early 1800s, with accompanying infrastructure (houses, commercial buildings, public buildings, roads, bridges, etc.), so many more people who could be affected now if a large earthquake were to happen. While we want to keep people safe from this potential hazard, we also want them to be able to continue to live and work in the area if they so choose.

The high hazard rating indicated on the National Seismic Hazard Maps is a direct contributor to depressed economic development in the area. Increased building costs and insurance rates are a direct result of the high hazard rating. Some businesses are prohibited from building in the area due to inability to meet federally mandated seismic requirements, while other businesses simply choose to go elsewhere to avoid bureaucratic red tape and risk of business loss. Fewer businesses in the area contributes directly to fewer jobs, resulting in a depressed economy in the region.

All of the questions and uncertainties in the science used to develop the NSHM series should encourage us to re-examine the map models and hazard rating criteria to see if the science supports the end products, the building codes and current public policies regarding seismic design and earthquake risk. The problem is really about what we do not know. Simple inability to agree on size of historic regional earthquakes and a basic attenuation model for the region should inform on the uncertainty of current science. Additionally, the long recurrence interval for these events begs reconsideration of seismic hazard assessment to lower than California levels: even if lower attenuation rates in the central United States makes a single large earthquake event risky to a larger geographic area, the lower population and longer recurrence interval should offset the magnitude of ground motion in a model that considers the complete scope of variables.

Ultimately, we can neither prove that a large earthquake will or will not happen or in what timeframe such an event might occur. We do not have conclusive answers. Much of the problem, then, has to do with how the scientific and historical data we have are applied. There are many people who have looked at the final product – not only the hazard maps but also the derived building codes and emergency management plans – and questioned whether the science actually supports the conclusions that have been drawn and the requirements that are in place. Local residents, businessmen and government officials want reassurance that their money, time and effort are being spent on something that is of real value to their community.

Limited funds require us to choose projects carefully. We cannot protect everyone from everything. At some point, we must decide what is the best we can do at a cost we can afford. Local concerns that building code requirements are too costly or that the level of seismic hazard identified by federal agencies is overstated for western Kentucky must be taken into consideration when determining an appropriate response. Similarly harmful are both the double standard of local versus federal standard differences, as well as the latitude allowed federal agencies to choose to which projects to apply seismic standards. What is the level of risk the local community is willing to incur? Is there a consensus? Has there been enough education to ensure that people are making informed decisions? And can the federal government modify its hazard assessment without exaggerating the results either positively or negatively in order to mitigate impacts on local economies?

Table 5.1: Scenario and NSHM Ground Motion Values. PGA, SA 0.3 and SA 1.0 minimum and maximum values listed in ascending value order for all scenario models, with the 2008 National Seismic Hazard Map (2% PE in 50 yrs.) values for these same ground motion parameters within the study region.

(a) PGA Minimum Values

Model ID	PGA Min. (g)
A 4026 72 10 / 20	0.007401
C 4026 72 10 / 20	0.008482
A 4026 77 00 / 10 / 20	0.010460
C 4026 77 00 / 10 / 20	0.013280
A 4026 82 10 / 20	0.014260
C 4027 71 10 / 20	0.014330
C 4026 82 10 / 20	0.019580
SW Fault 1	0.020000
C 4027 75 10 / 20	0.020120
A 4027 71 10 / 20	0.021530
C 4028 74 10 / 20	0.021920
C 4027 79 10 / 20	0.028110
A 4027 75 10 / 20	0.028600
C 4028 78 10 / 20	0.030560
A 4028 74 10 / 20	0.035330
A 4027 79 10 / 20	0.037130
C 4028 81 10 / 20	0.037760
A 4028 78 10 /20	0.046190
A 4028 81 10 / 20	0.055640
NSHM (2% 50 yr) PGA	0.064186

(b) PGA Maximum Values

Model ID	PGA Max. (g)
SW Fault 1	1.100
C 4027 71 10 / 20	1.447
C 4026 72 10 / 20	1.517
C 4028 74 10 / 20	1.657
C 4027 75 10 / 20	1.700
C 4026 77 00 / 10 / 20	1.854
C 4028 78 10 / 20	1.943
NSHM (2% 50 yr) PGA	1.983
C 4027 79 10 / 20	1.992
C 4028 81 10 / 20	2.185
A 4027 71 10 / 20	2.210
C 4026 82 10 / 20	2.253
A 4026 72 10 / 20	2.308
A 4028 74 10 / 20	2.506
A 4027 75 10 / 20	2.607
A 4026 77 00 / 10 / 20	2.809
A 4028 78 10 /20	2.910
A 4027 79 10 / 20	3.011
A 4028 81 10 / 20	3.210
A 4026 82 10 / 20	3.308

(c) SA 0.3 Minimum Values

Model ID	SA 0.3 Min. (g)
C 4026 72 10 / 20	0.01908
SW Fault 1	0.02000
C 4026 77 00 / 10 / 20	0.02891
A 4026 72 10 / 20	0.02942
C 4027 71 10 / 20	0.03794
A 4026 77 00 / 10 / 20	0.04013
C 4026 82 10 / 20	0.04081
C 4027 75 10 / 20	0.05193
A 4026 82 10 / 20	0.05199
C 4028 74 10 / 20	0.05911
C 4027 79 10 / 20	0.06947
C 4028 78 10 / 20	0.07909
A 4027 71 10 / 20	0.08601
C 4028 81 10 / 20	0.09483
A 4027 75 10 / 20	0.11150
A 4027 79 10 / 20	0.13990
A 4028 74 10 / 20	0.13880
NSHM (2% 50 yr) SA 0.3	0.14055
A 4028 78 10 /20	0.17570
A 4028 81 10 / 20	0.20530

Table 5.1: Scenario and NSHM Ground Motion Values (cont.).

(d) SA 0.3 Maximum Values

Model ID	SA 0.3 Max. (g)
SW Fault 1	1.3800
C 4027 71 10 / 20	1.9830
C 4026 72 10 / 20	2.1020
C 4028 74 10 / 20	2.3400
C 4027 75 10 / 20	2.4230
C 4026 77 00 / 10 / 20	2.6480
C 4028 78 10 / 20	2.7730
C 4027 79 10 / 20	2.8430
C 4028 81 10 / 20	3.0860
C 4026 82 10 / 20	3.1600
NSHM (2% 50 yr) SA 0.3	3.5735
A 4027 71 10 / 20	3.7600
A 4026 72 10 / 20	3.9140
A 4028 74 10 / 20	4.2170
A 4027 75 10 / 20	4.3650
A 4026 77 00 / 10 / 20	4.6490
A 4028 78 10 /20	4.7850
A 4027 79 10 / 20	4.9140
A 4028 81 10 / 20	5.1540
A 4026 82 10 / 20	5.2630

(e) SA 1.0 Minimum Values

Model ID	SA 1.0 Min. (g)
SW Fault 1	0.020000
C 4026 72 10 / 20	0.022090
C 4026 77 00 / 10 / 20	0.034110
A 4026 72 10 / 20	0.037590
C 4027 71 10 / 20	0.043110
C 4026 82 10 / 20	0.047700
A 4026 77 00 / 10 / 20	0.053250
C 4027 75 10 / 20	0.060880
NSHM (2% 50 yr) SA 1.0	0.066197
C 4028 74 10 / 20	0.069200
A 4026 82 10 / 20	0.069880
C 4027 79 10 / 20	0.080990
C 4028 78 10 / 20	0.092950
A 4027 71 10 / 20	0.108700
C 4028 81 10 / 20	0.111300
A 4027 75 10 / 20	0.146200
A 4028 74 10 / 20	0.180500
A 4027 79 10 / 20	0.187100
A 4028 78 10 /20	0.234200
A 4028 81 10 / 20	0.271900

(f) SA 1.0 Maximum Values

Model ID	SA 1.0 Max. (g)
SW Fault 1	1.1400
NSHM (2% 50 yr) SA 1.0	1.3041
C 4027 71 10 / 20	1.6280
C 4026 72 10 / 20	1.7390
C 4028 74 10 / 20	1.9590
C 4027 75 10 / 20	2.0430
C 4026 77 00 / 10 / 20	2.2680
C 4028 78 10 / 20	2.3840
C 4027 79 10 / 20	2.4580
C 4028 81 10 / 20	2.6510
C 4026 82 10 / 20	2.7010
A 4027 71 10 / 20	4.0220
A 4026 72 10 / 20	4.2220
A 4028 74 10 / 20	4.6120
A 4027 75 10 / 20	4.7990
A 4026 77 00 / 10 / 20	5.1500
A 4028 78 10 /20	5.3120
A 4027 79 10 / 20	5.4630
A 4028 81 10 / 20	5.7280
A 4026 82 10 / 20	5.8390

(a)

(b)

Figure 5.1: Farmers' Houses in Southeastern Gansu Province. (a) A traditional adobe house and (b) a recently constructed seismic-resistant house. Traditionally built adobe houses suffered severe damage during the 2008 Wenchuan earthquake while houses built to seismic-resistant standards under the government subsidized mitigation program sustained little or no damage. Photos: ©Zhenming Wang 2008.

CHAPTER 6: RECOMMENDATIONS

Whether justified or not, there is great local perception in western Kentucky that overstated seismic hazard classification has led to overly stringent building codes and other detrimental public policies, ultimately suppressing the growth of local economy through increased building and insurance costs, general inconvenience, and fear of increased economic and safety risks. The underlying science of the National Seismic Hazard Maps drives seismic hazard classification for the New Madrid Seismic Zone in general, including western Kentucky, by setting the earthquake hazard levels and specifications that are then used to develop engineering and building codes. As with most situations involving human interaction, there is unlikely to be a one-size-fits-all solution for all circumstances, but some measures can be taken to address real or perceived effects of living and working in a higher earthquake hazard region.

6.1 Research

1. Continue earthquake monitoring and research. First and foremost, current monitoring of regional seismicity and research into causative mechanisms and paleoseismic studies must continue in order to increase the knowledge base for the New Madrid Seismic Zone. New directions for research such as the recent forays into monitoring and explaining strain through GIS data should continue to be developed to broaden our understanding of geoscience principles. Research into seismic attenuation functions should continue to narrow the uncertainty in ground motion expectations for modeling purposes.

2. Develop new construction technologies and materials. New construction materials or improved procedures for utilizing existing materials will allow for construction options, potentially allowing project managers to better control costs while still meeting seismic standards.

3. Create cost benefit analyses. At a minimum, a cost analysis considering indirect costs of meeting seismic requirements should be done to complement the recent construction cost benefit analysis. Indirect costs may include design and permitting costs, additional wage costs for employee time required to comply with seismic design requirements, and required or desirable insurance costs, among others.

4. Continue to improve hazard and risk analysis tools. Many tools for hazard and risk analysis such as the NSHM series, the USGS Worldwide Seismic Design Values tool and FEMA's Hazus software for economic analysis have been developed by various government agencies and are available for public use. These tools and others should continue to be developed and documentation and training should be provided for their correct use. Improvements to Hazus could include items such as improving underlying databases for more complete soils geology, CEUS faults, populations, and building types and distributions; improving attenuation models; and reducing uncertainties in mathematical calculations to reduce the high (documented) overstatement of hazard by Hazus models.

6.2 Education

1. Improve the transfer of information to the public. As science becomes more complex, the public must rely more on experts to collect and interpret data and communicate information in an unbiased manner. On the federal level, improve the level of trust between the public and seismic experts by increasing transparency in communication with more understandable and more available documentation of data, information, methods, and products. Understand how the data and information affect the public and respond appropriately to concerns about the underlying science.

2. Provide opportunities for additional education for non-scientists. Federal, state and local seismic experts should provide joint opportunities for general education in layman's terms to members of the non-science-based public. Topics should include general earthquake information as well as specific information for geographic regions. Both certainties and uncertainties should be clarified, along with the way in which uncertainties are incorporated into scientific output products such as hazard maps, building codes, and emergency preparedness plans. Both likely and worst-case scenarios should be communicated, with emphasis given to explanation of probability rather than scare tactics.

3. Provide opportunities for additional education for structural design and construction professionals. Federal, state and local experts should provide joint opportunities for continuing or targeted education for professionals such as engineers, architects, builders, and others regarding current science. By working together, experts will better see the range of topics and concerns that might not be obvious when focusing

on jurisdictional topics only. Topics should include known and unknown factors, level of certainty of current science, existing tools for seismic analysis and appropriate uses, etc. This recommendation could be worked into the requirement of some professions for continuing education.

4. Provide suggestions for appropriate emergency response plans and preparation activities. It has been noted that although seismic hazard is considered high in western Kentucky, few guidelines exist for hospitals and other care facilities for appropriate response to seismic events. Although there are general emergency response plans in place at all medical facilities, there is little or no understanding of a realistic scenario for a given expected or potential earthquake event, and therefore no way to adequately prepare for emergency response. On both state and local levels, it would be wise to provide probable scenarios for the after-effects of earthquakes of various magnitudes with various sources. A range of scenarios would allow emergency responders to develop appropriate plans for emergency management and response. The likelihood of aftershocks to a large earthquake event, the probability of disruption of local utilities or public services, and a realistic expectation of local buildings and infrastructure that would be destroyed or remain functional should all be considered. The USGS Great Shake-Out has many resources that could be modified for this purpose, but scenarios must be somewhat customized to local conditions in order for emergency responders to prepare appropriately.

6.3 Policy/Application

In addition to educating local residents, developers and government officials about the real if undefined seismic hazard potential, uncertainties in the science models and maps should be acknowledged by those who translate the science into engineering and public policy uses. Consideration of uncertainties should be given when applications are developed so that benefits and costs of applying the science are more evenly weighted for local communities.

1. Justify or revise high levels of NMSZ earthquake hazard on the NSHM series. On the federal level, consider appropriate changes to the central and eastern U.S. (CEUS) NSHM to account for uncertainties in the science. Simple back-of-the-envelope assumptions about earthquake magnitudes, locations and recurrence intervals discredit the current maps which indicate higher earthquake hazard in the NMSZ than in the more

often and more highly seismic California fault zones. The most logical place for adjustment is in the weighting given to various factors during PSHA calculations, or in adoption of other hazard analysis methods such as DSHA. Although map documentation indicates the CEUS hazard levels were reduced between the 2002 and 2008 map versions, later revisions have restored the hazard levels to very nearly the same level as on the 2002 maps. However, neither current nor historic activity supports this analysis. If current hazard levels are justifiable, explain the reasoning more clearly.

2. Open a forum for revisions to state building code seismic requirements. State and local building codes are under the jurisdiction of the building code adopted by the State of Kentucky, which has been modified from the International Building Code. Although the code has been developed by professionals, it is possible that objections or problems will be encountered during the application of code requirements. A forum for discussion of problems and suggested changes to the building code should be established for professionals tasked with implementing code requirements.

3. Establish assistance for non-professionals for individual residential projects. Establish state-level assistance for residential building code compliance to help private (non-professional) individuals obtain appropriate permits and approvals for residential home construction projects. This recommendation is made to address concerns that private homeowners have inadequate access to affordable design services for individual home building projects. Licensed engineers or other design professionals are reluctant to take on small single-residence projects, or associated fees are considered too high for personal budgets (as opposed to larger scale commercial projects with comparatively larger budgets), and local officials run the risk of conflict of interest for advising on individual projects. An avenue is needed to provide necessary advice and services to individuals at affordable rates to maintain residential building.

4. Customize Hazus for area-specific economic analyses of potential hazards. In order to help state and local officials prepare for potential large earthquake events, Hazus scenarios should be customized with updated building, population and soils databases. Additional scenarios for fault hazards should be developed rather than relying on minimal point-source hazard scenarios included with the software package. Resulting scenario analyses using more specific local data will point out weak areas of

local buildings and infrastructure and help state and local agencies determine where best to assign available funds for reconstruction and emergency preparedness projects.

5. Be aware of worst-case scenarios, but plan and prepare for likely scenarios. State and local agencies responsible for emergency planning and response should collaborate with each other and the public to prepare for likely events at all levels. Some consideration for extreme events should be made by agencies, but focus should be on common sense self-help expectations for the general public. Public school elementary programs should include regular instruction to children on appropriate response to earthquake events without fright tactics.

As stated by one interviewee, ultimately, in order for science to help communities, it must be more than applicable: it must be compelling (L. Peters, personal communication, 2013). It is to the benefit of professionals at all levels to make sure current science is both applicable and compelling within communities.

APPENDIX A: PRELIMINARY INTERVIEW QUESTIONS

NMSZ Policy and Economics Interview Questions:

1. Please state your name and occupation, and provide preferred contact information (phone and/or email).

2. How long have you worked in this or a related occupation? in this geographic region?

3. Please tell me about your work and how seismic hazard relates to it.

4. What do you know about the seismic hazard for your geographic area? (magnitude, ground motion, frequency of recurrence, location/description of possible seismic sources)

5. Are you familiar with the National Seismic Hazard Map (NSHM) series?

6. What is your opinion of the NSHM for the central U.S.?

7. Describe the process you use to make decisions regarding seismic hazard.

8. How does the central U.S. NSHM influence decisions you make regarding seismic hazard?

9. In what ways does the central U.S. NSHM affect the local economy? (consider construction costs, ability to secure loans, job growth/loss, costs transferred to businesses and/or individuals, etc.)

10. What costs are related to seismic hazard analysis? At what value are the costs no longer feasible for development? (perhaps as a project percentage if not as an actual dollar amount)

11. In what ways does the central U.S. NSHM affect local public policy decisions? (consider engineering/building codes, emergency preparedness, etc.)

12. Are you familiar with the science and decision process for development and revision of the NSHM?

13. What changes in the NSHM development and revision process would improve the published maps?

14. Do you have any other comments related to the NSHM or seismic hazard in general as they affect the local economy or public policy?

APPENDIX B: INSTRUCTIONS FOR RECREATING HAZUS MODELS

Scenario earthquake ground motion and relative economic analyses were performed using FEMA's Hazus-MH software, version 2.1. Instructions follow to recreate the scenario models generated for this study. Screen name identifiers are in **Bold**. Option button identifiers are in *italics*. Keyboard buttons are identified by all capital letters within triangle brackets (for example, <CTRL>).

Create a Study Region

1. Double click the Hazus-MH 2.1 desktop icon to start the program.
2. From the **Hazus-MH Startup** menu, click *Create a new region*.
3. Click *OK*.
4. On the **Create New Region** screen, click *Next* to start the wizard.
5. Enter a name for your region. I entered a name that identified the general characteristics of the region (example: NMSZ Central Counties), then later duplicated this base region to create each individual scenario model, giving the individual models their own identifying names. In this way, each model gets saved as a separate study region for ease of data access.
6. Optionally, enter a description of the region for future reference.
7. Click *Next*.
8. Check *Earthquake* to indicate the hazard type.
9. Click *Next*.
10. Click *Census tract* to indicate the aggregation level.
11. Click *Next*.
12. From the scrolling list, click *Arkansas (AR)* to select it, then scroll down and press <CTRL> while clicking *Illinois (IL)*, *Indiana (IN)*, *Kentucky (KY)*, *Mississippi (MS)*, *Missouri (MO)*, and *Tennessee (TN)* to select all seven states from the list.
13. Click *Next*.
14. Use the same process to choose the counties within each state. A list of counties is included in Appendix C.
15. Click *Next*.
16. To select all census tracts in all selected counties, click *Show map*.
17. From the icon bar, hover over the icons to identify the *Select All* icon, 8th icon from the left. Click the *Select All* icon.
18. Click *Selection Done*.
19. Click *Next*.
20. Click *Finish*. It will take about 40 minutes for Hazus to create the study region. When it has completed, a pop-up message will indicate "Region aggregation successful."
21. Click *OK*.

Set Base Study Region Characteristics

1. From the **Hazus-MH Startup** menu, click *Open a region*.
2. Click *OK*.
3. Click *Next*.
4. Click the name of the region to select it from the available region list.
5. Click *Next*.

6. Click *Finish*.
7. When the study region opens, click the dropdown arrow next to the *Add Data* icon.
8. Click *Add Data From ArcGIS Online*.
9. Locate the **USA States** package under **Featured**; click *Add*.
10. On the **Geographic Coordinate Systems Warning** menu, click *Transformations*.
11. On the **Convert from** list, click *GCS_WGS_1984*.
12. Click *OK*.
13. Click *Close*.
14. In the **Table of Contents** sidebar, select the *List By Drawing Order* icon.
15. Right click the **USA States** label.
16. Click *Properties*.
17. Click the **Display** tab.
18. Change **Transparency** to 70%.
19. Click *OK*.
20. Repeat steps 7-19 to add the **USA Counties** layer to the base region.
21. Click the *Save* icon.
22. Close Hazus.

Duplicate the Base Region and Create the Point-Source Scenario Models

For example purposes, model CC C 4026 77 10 will be created here. Within this model name, CC indicates the Central Counties region, C designates the CEUS 2008 attenuation function, 4026 designates the historical event epicenter (for the 12/16/1811 event), 77 indicates a magnitude of 7.7, and 10 indicates a depth of 10 km. This process must be repeated to create each point-source scenario model.

1. Double click the Hazus-MH 2.1 desktop icon to start the program.
2. From the **Hazus-MH Startup** menu, click *Duplicate a region*.
3. Click *OK*.
4. From the list of available regions, click the name of the base study region.
5. Click *Duplicate.*
6. Click *Yes*.
7. Enter a name for the new region. I used the scenario model numbers as names for duplicate regions (example: CC C 4026 77 10). Each duplicate region will later be customized for appropriate model variables.
8. Optionally, enter a description of the region for future reference.
9. Click *OK*.
10. When the region has been duplicated, a pop-up message will indicate, "Region duplicate completed." Click *OK*.
11. On **Duplicate Region** menu, click *Done*.
12. On the **Hazus-MH Startup** menu, click *Open a region*.
13. Click *OK*.
14. On the **Open Region** screen, click *Next* to start the wizard.
15. Select the name of the region just duplicated from the base study region (example: CC C 4026 77 10).
16. Click *Next*.
17. Click *Finish*. Hazus will open the region.
18. To define the scenario hazard, on the main menu bar, click *Hazard*.
19. Click *Scenario*.
20. On the **Scenario Wizard** screen, click *Next*.
21. Select *Define a new scenario*.

22. Click *Next*.
23. Select *Historical epicenter event*.
24. Click *Next*.
25. Click **EventDate** to highlight the column.
26. Right click **EventDate** and click *Sort* to sort the available dates chronologically.
27. Scroll down to the desired historical event date (for this example, 4026) and click anywhere in the row to highlight that event.
28. Click *Next*.
29. Click the drop down arrow, then select the appropriate attenuation function from the list. For this example, the default *Central & East US (CEUS 2008)* is correct.
30. Click *Next*.
31. Highlight the **Moment magnitude** value and overwrite it with the correct value for the scenario you are creating (for this example, *7.7)*.
32. If necessary, highlight the **Depth** value and overwrite it with the correct value for the scenario you are creating. For this example, the default of 10 km is correct.
33. Click *Next*.
34. Enter a name for the hazard scenario you are creating. I used the abbreviations for the variables involved; for this example, *C 4026 77 10*. This hazard scenario will be saved and could be accessed later for use within a different region, perhaps a small section of the base study region.
35. Click *Next*.
36. Click *Finish*.
37. To run the hazard analysis, on the main menu bar, click *Analysis*.
38. Click *Run*.
39. On the **Analysis Options** menu, click *Select All*.
40. Click *No* to allow Hazus to generate ground motion contour maps for the scenario model.
41. Click *OK*.
42. Click *Yes* to begin the analysis process. It will take about 7-8.5 hours for Hazus to run the complete analysis. When it has finished, a pop-up message will indicate "Analysis completed successfully."
43. Click *OK*.
44. Click the **Save** icon to save the analysis.
45. To add layers for ground motion contours, on the main menu bar, click *Results*.
46. Scroll down to *Ground Motion or Ground Failure*, then click *Contours or Ground Failure Maps* from the drop-down menu.
47. Click the desired ground motion function (example: *PGA Contour*).
48. Click *Map*.
49. Repeat Steps 46 and 47 until layers for each desired ground motion have been mapped. For this study, I used PGA, Spectral Acceleration at 0.3 sec and Spectral Acceleration at 1.0 sec.
50. When all desired ground motion contour layers have been added, click *Cancel*.
51. To generate Global Summary Reports, on the main menu bar, click *Results*.
52. On the drop-down menu, click *Summary Reports*.
53. On the **Hazus-MH Earthquake Summary Reports** screen, click the **Other** tab.
54. Click *Global Summary Report*.
55. Click *View*.
56. When the report appears, save it to a desired location and format.
57. Close the report.
58. On the **Hazus-MH Earthquake Summary Reports** screen, click *Close*.
59. Repeat Steps 1-58 for each point-source scenario model.

Download and Format Data for the Fault Line Scenario Model

Shapefiles for PGA, PGV, SA 0.3 and SA 1.0 values must be input into a GeoDatabase using ESRI's ArcCatalog software.

1. Save the shape files for the fault line model to the Inventory folder created for Hazus data. For this project, we used data developed by the USGS for scenario NLE2011NMSZ7.7_se. Downloaded data shapefiles were saved to HazusData\Inventory\NLE2011NMSZ77_SE.
2. Start ESRI's **ArcCatalog**.
3. Click on the file folder where the data are located (see Step 1.)
4. On the main menu, click *File*.
5. Hover over *New*, then click *Personal Geodatabase* on the drop-down list.
6. Change the name to something appropriate (example: SWFaultMaps), then press <ENTER>. Do not use any spaces in the name.
7. In the catalog tree, click the plus symbol next to the folder where the shape files are located.
8. From the extended list, click the first shape file (*pga*).
9. Right click the shapefile name.
10. On the drop-down menu, hover over *Export*, then click *To Geodatabase (single)*.
11. In the **Feature Class to Feature Class** dialog box, next to **Output Location**, click the *Browse* button.
12. Click the drop-down arrow for the Look in: menu and select the geodatabase created above.
13. Click *Add*.
14. In the **Output Feature Class** box, type a name for the feature class (example: *pga*).
15. In the **Field Map (optional)** box, right click *VALUE_(Double)*.
16. Click *Properties*.
17. In the **Name** box, enter *ParamValue*.
18. In the **Alias** box, enter *ParamValue*.
19. In the **Type** box, select *Double*.
20. In the **Properties** box, set **Precision** to *13*, **Scale** to *4*, and **Allow NULL values** to *Yes*.
21. In the **Merge Rule** box, select *First*.
22. Leave the **Delimiter** box blank.
23. Click *OK*.
24. In the **Feature Class to Feature Class** dialog box, click *Environments*.
25. Click *Output Coordinates*.
26. Click the browse button next to Output Coordinate System.
27. Navigate to the Hazus-MH\Data folder. This is the folder where Hazus-MH is installed. By default it is C:\Program Files\HAZUS-MH\Data if not changed during program installation.
28. Double click *USGS.mdb*.
29. Click *USGS* to select the feature class.
30. Click *Add*.
31. Click *OK*.
32. Click *OK* again.
33. When the Feature Class to Feature Class check box pops up indicating successful completion, close the pop-up box.
34. Repeat Steps 8-33 to add the other shape files to the same geodatabase.
35. When all shape files have been added, close **ArcCatalog**.

Duplicate the Base Region and Create the Fault Line Scenario Model

1. Follow Steps 1-17 under **Duplicate the Base Region and Create the Point-Source Scenario Models** instructions above to create and open the new model. Choose an appropriate model name (example: Fault 1).
2. To define the scenario hazard, on the main menu bar, click *Hazard*.
3. Click *Data Maps*.
4. Click *Add map to list*.
5. Navigate to the GeoDatabase created in **Download and Format Data for the Fault Line Scenario Model** above.
6. Double click the GeoDatabase name.
7. Enter an appropriate map name (example: *PGA*) for the contour map you are adding.
8. In the **Map type** drop-down menu, select the "User-defined" option for the particular map you are adding (example: *User-defined for pga*).
9. In the Table name scroll box, select the correct table name from the ones you added earlier (example: *pga*).
10. Click *OK*.
11. Repeat Steps 4-10 to add maps for PGA, PGV, SA 1.0, and SA 0.3 contours to your base study region map.
12. Click *Close*.
13. To define the fault line scenario, on the main menu, click *Hazard*.
14. Click *Scenario*.
15. On the **Scenario Wizard** screen, click *Next*.
16. Click *Define a new scenario*.
17. Click *Next*.
18. Click *User-supplied hazard*.
19. Click *Next*.
20. Select the *Ground Shaking* tab.
21. From the drop-down lists, select the appropriate data source for each contour map from the maps you added above.
22. In the **Magnitude generating the event**, enter *7.7*, which is the magnitude designated for this scenario event as designed by the USGS.
23. Click *Next*.
24. Enter a name for the scenario event (example: Fault event).
25. Click *Next*.
26. Click *Finish*.
27. To run the hazard analysis, on the main menu bar, click *Analysis*.
28. Click *Run*.
29. On the **Analysis Options** menu, click *Select All*.
30. Click *No* to allow Hazus to generate ground motion contour maps for the scenario model.

41. Click *OK*.
42. Click *Yes* to begin the analysis process. It will take about 9-10 hours for Hazus to run the complete analysis. When it has finished, a pop-up message will indicate "Analysis completed successfully."
43. Click *OK*.
44. Click the **Save** icon to save the analysis.
45. To map the ground motion contours which were input for the hazard scenario, on the main menu, click *Hazard*.
46. Click *Show Current*.

47. On the **Current Scenario** tab, click the desired map to select it (example: *PGA*).
48. Click *Map*. The contour will appear as a layer in the **Table of Contents** and will be displayed.
49. Repeat Steps 47 and 48 to map the remaining contours as desired.
50. To map the ground motions as products of the census tracts and to produce Global Summary Reports, follow Steps 45-59 under **Duplicate the Base Region and Create the Point-Source Scenario Models** above.

APPENDIX C: STATES AND COUNTIES INCLUDED IN HAZUS ECONOMIC ANALYSES

ARKANSAS

Arkansas
Clay
Craighead
Crittenden
Cross
Desha
Fulton
Greene
Independence
Izard
Jackson
Lawrence
Lee
Lonoke
Mississippi
Monroe
Phillips
Poinsett
Prairie
Randolph
Saint Francis
Sharp
White
Woodruff

ILLINOIS

Alexander
Clay
Clinton
Edwards
Franklin
Gallatin
Hamilton
Hardin
Jackson
Jefferson
Johnson
Lawrence
Marion
Massac
Monroe
Perry
Pope
Pulaski
Randolph
Richland
Saint Clair
Saline
Union
Wabash
Washington
Wayne
White
Williamson

INDIANA

Gibson
Knox
Pike
Posey
Spencer
Vanderburgh
Warrick

KENTUCKY

Ballard
Butler
Caldwell
Calloway
Carlisle
Christian
Crittenden
Daviess
Fulton
Graves
Hancock
Henderson
Hickman
Hopkins
Livingston
Logan
Lyon
Marshall
McCracken
McLean
Muhlenberg
Ohio
Todd
Trigg
Union
Webster

MISSISSIPPI

Alcorn
Benton
Bolivar
Calhoun
Carroll
Chickasaw
Clay
Coahoma
Desoto
Grenada
Itawamba
Lafayette
Lee
Leflore
Marshall
Monroe
Montgomery
Panola
Pontotoc
Prentiss
Quitman
Sunflower
Tallahatchie
Tate
Tippah
Tishomingo
Tunica
Union
Webster
Yalobusha

MISSOURI

Bollinger
Butler
Cape Girardeau
Carter
Crawford
Dent
Dunklin
Howell
Iron
Jefferson
Madison
Mississippi
New Madrid
Oregon
Pemiscot
Perry
Reynolds
Ripley
Saint Francois
Sainte Genevieve
Scott
Shannon
Stoddard
Washington
Wayne

TENNESSEE

Benton
Carroll
Cheatham
Chester
Crockett
Davidson
Decatur
Dickson
Dyer
Fayette
Gibson
Giles
Hardeman
Hardin
Haywood
Henderson
Henry
Hickman
Houston
Humphreys
Lake
Lauderdale
Lawrence
Lewis
Madison
Marshall
Maury
McNairy
Montgomery
Obion
Perry
Robertson
Shelby
Stewart
Tipton
Wayne
Weakley
Williamson

APPENDIX D: SELECTED HAZUS GROUND MOTION CONTOUR MAPS

This appendix includes PGA, SA 1.0 and SA 0.3 regional contour maps for the following scenario models:

A 4026 72 10

A 4026 77 10

A 4026 82 10

A 4027 71 10

A 4027 75 10

A 4027 79 10

A 4028 74 10

A 4028 78 10

A 4028 81 10

C 4026 72 10

C 4026 77 10

C 4026 82 10

C 4027 71 10

C 4027 75 10

C 4027 79 10

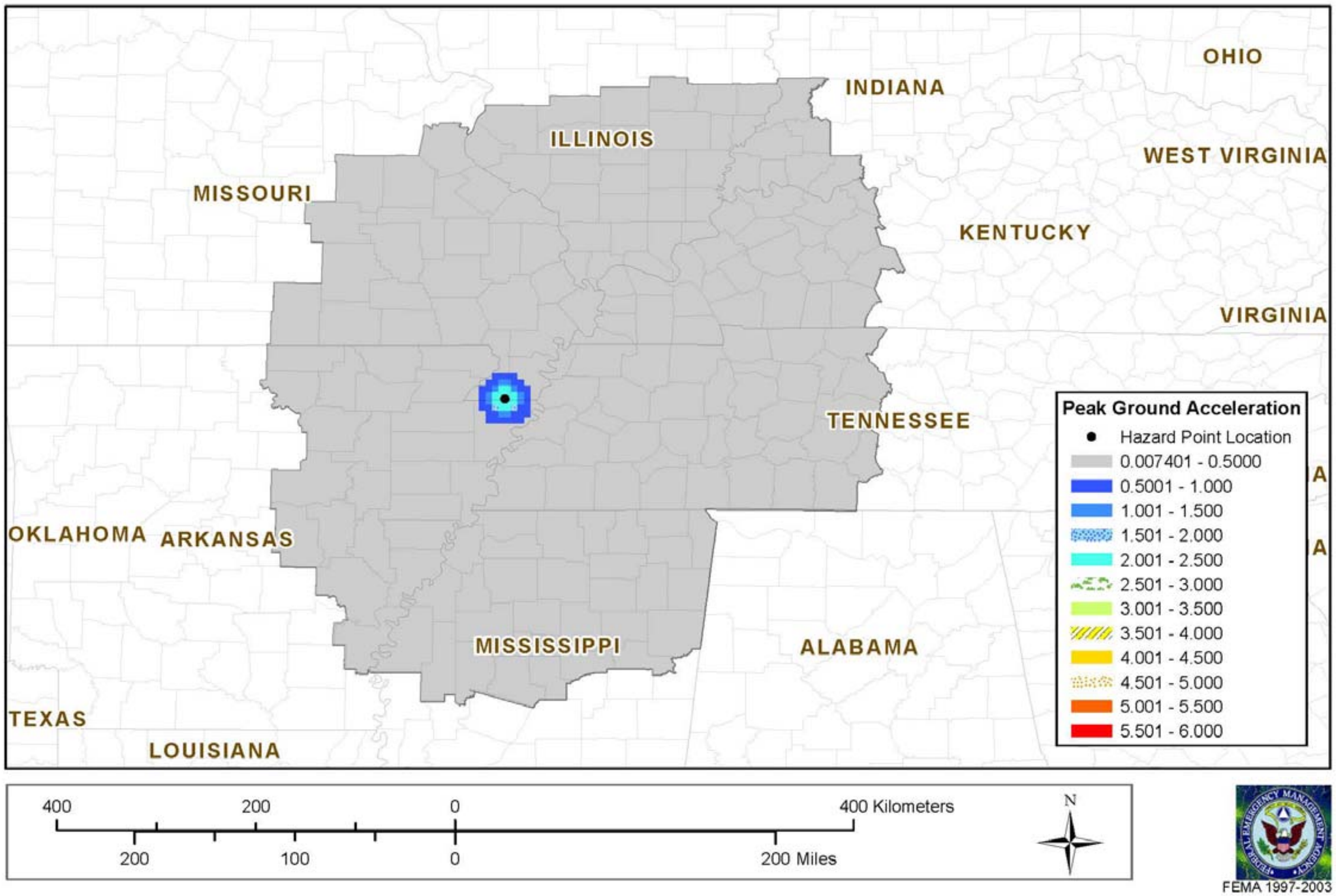
C 4028 74 10

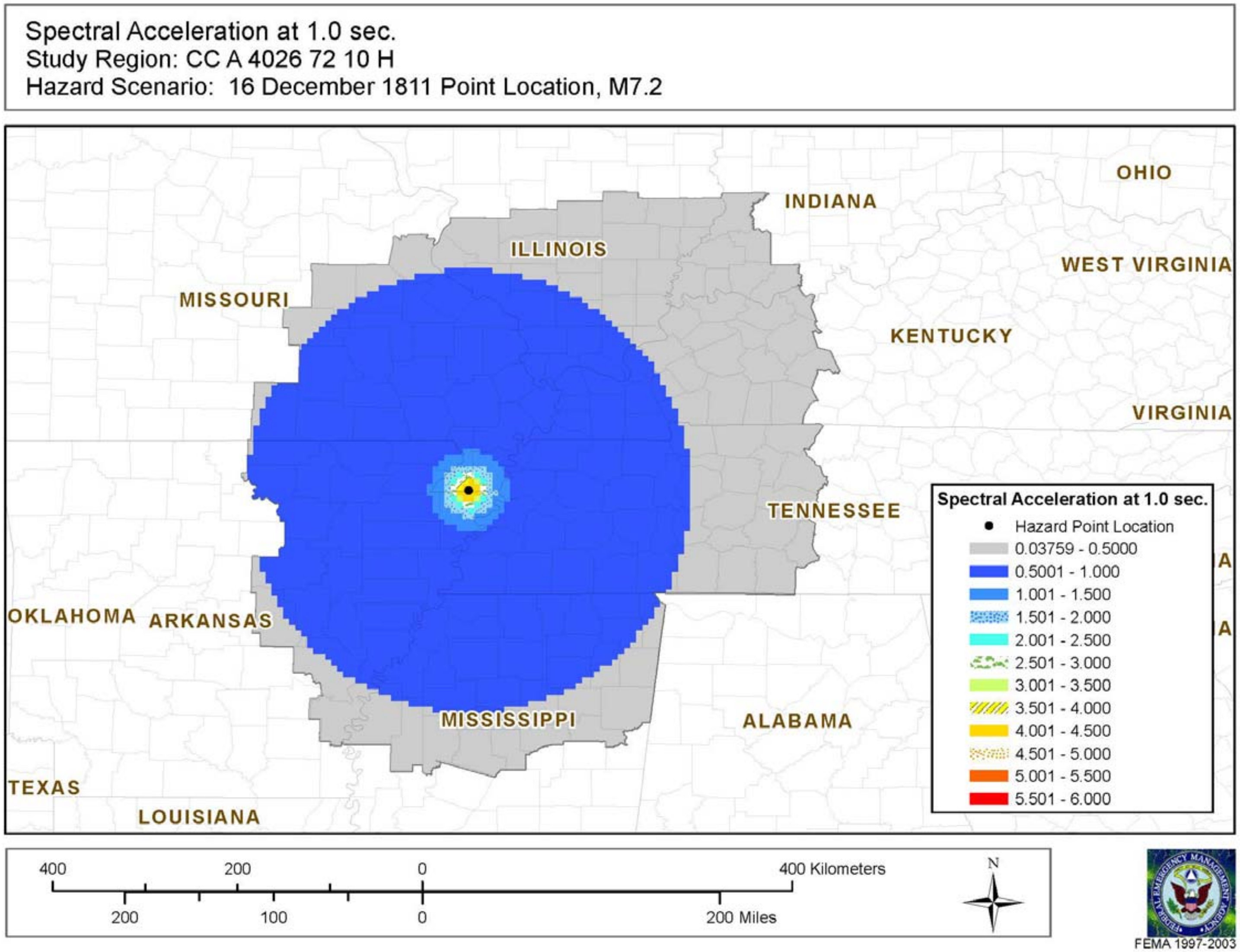
C 4028 78 10

C 4028 81 10

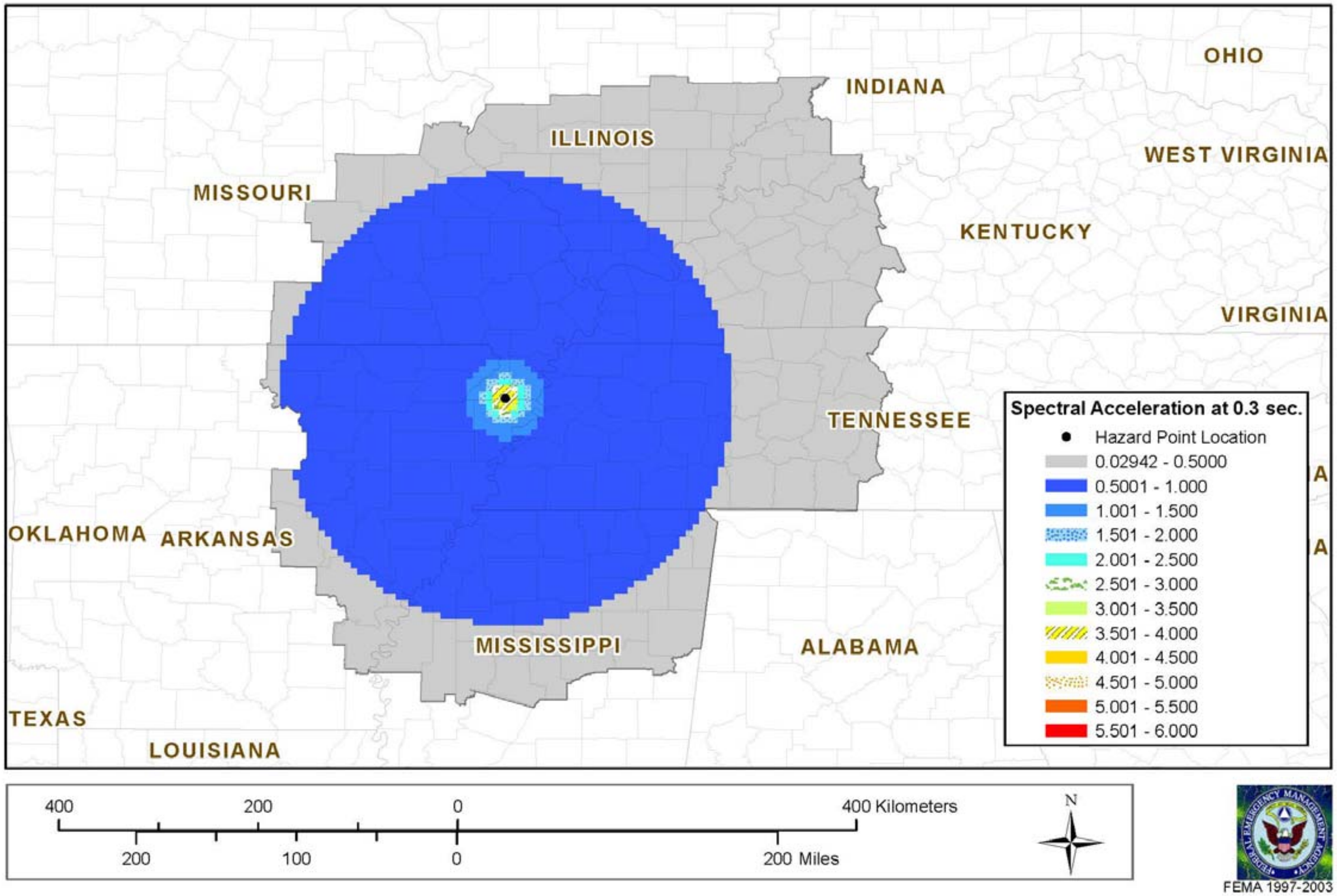
SW Fault 1

Peak Ground Acceleration
Study Region: CC A 4026 72 10 H
Hazard Scenario: 16 December 1811 Point Location, M7.2

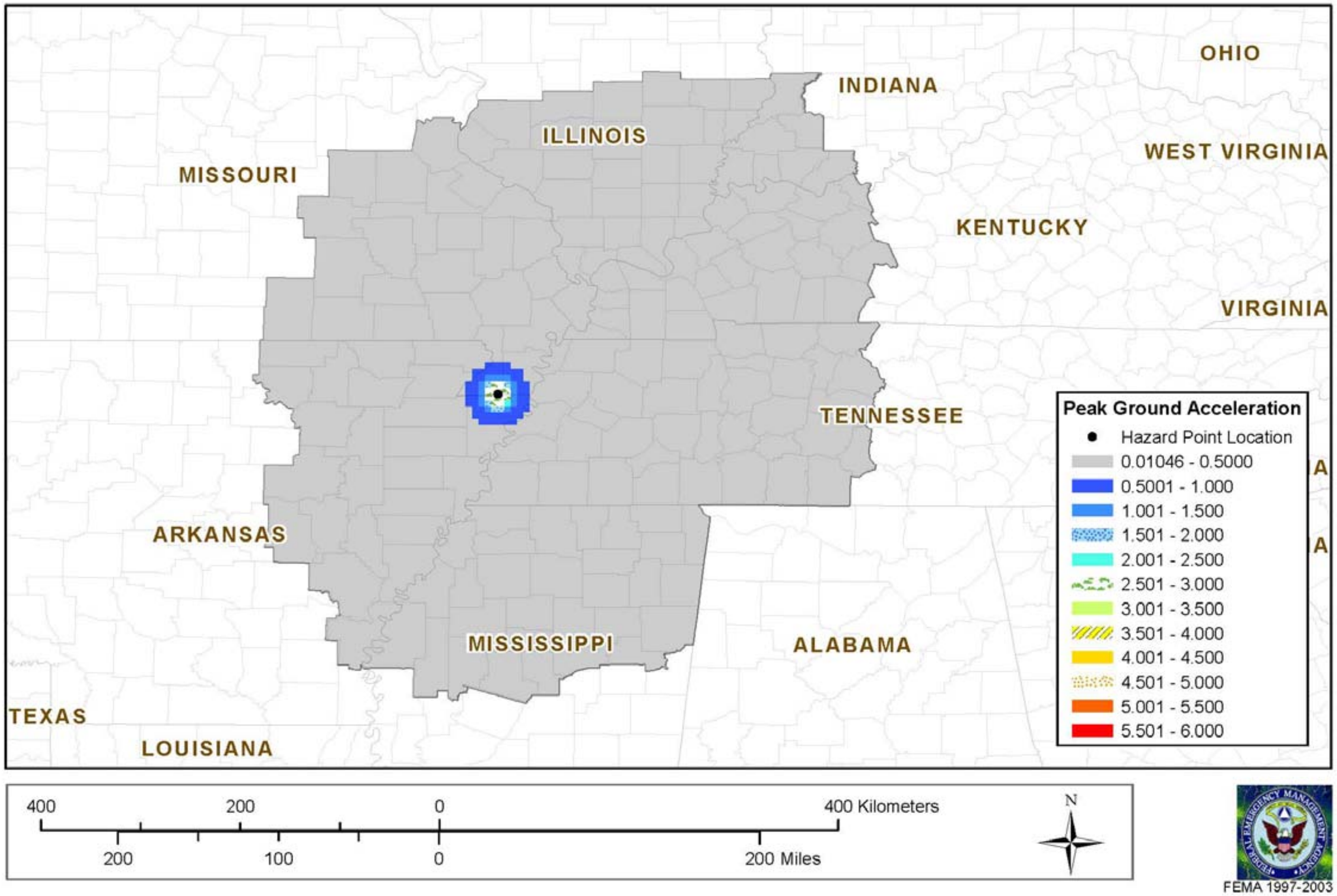



Spectral Acceleration at 1.0 sec.
Study Region: CC A 4026 72 10 H
Hazard Scenario: 16 December 1811 Point Location, M7.2
OHIO
INDIANA
ILLINOIS
WEST VIRGINIA
MISSOURI
KENTUCKY
VIRGINIA
TENNESSEE
OKLAHOMA
ARKANSAS
MISSISSIPPI
ALABAMA
TEXAS
LOUISIANA
Spectral Acceleration at 1.0 sec.
Hazard Point Location
0.03759 - 0.5000
0.5001 - 1.000
1.001 - 1.500
1.501 - 2.000
2.001 - 2.500
2.501 - 3.000
3.001 - 3.500
3.501 - 4.000
4.001 - 4.500
4.501 - 5.000
5.001 - 5.500
5.501 - 6.000
400 200 0 400 Kilometers
200 100 0 200 Miles
N
FEMA 1997-2003

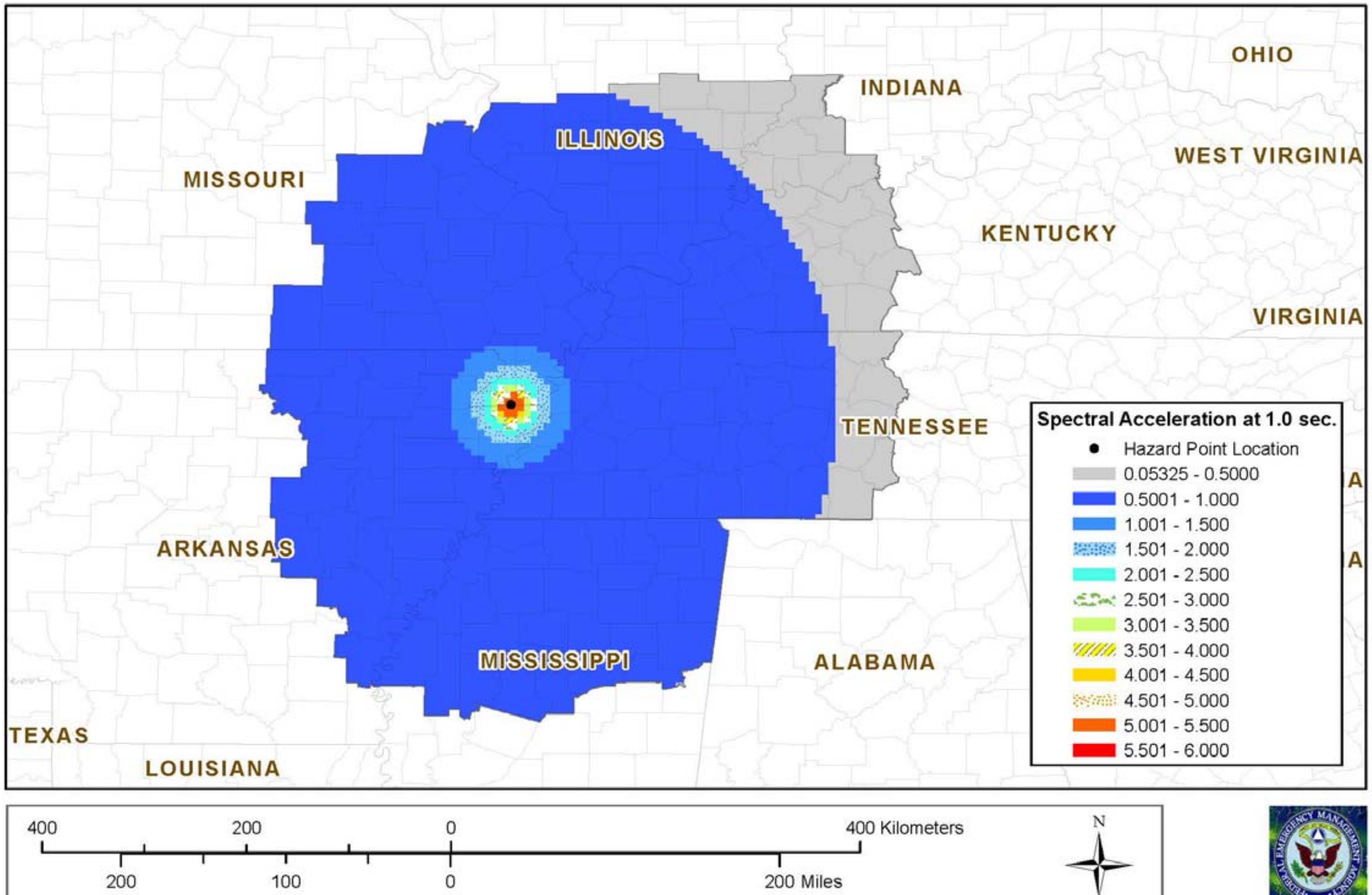
Spectral Acceleration at 0.3 sec.
Study Region: CC A 4026 72 10 H
Hazard Scenario: 16 December 1811 Point Location, M7.2



Peak Ground Acceleration
Study Region: CC A 4026 77 10 H
Hazard Scenario: 16 December 1811 Point Location, M7.7

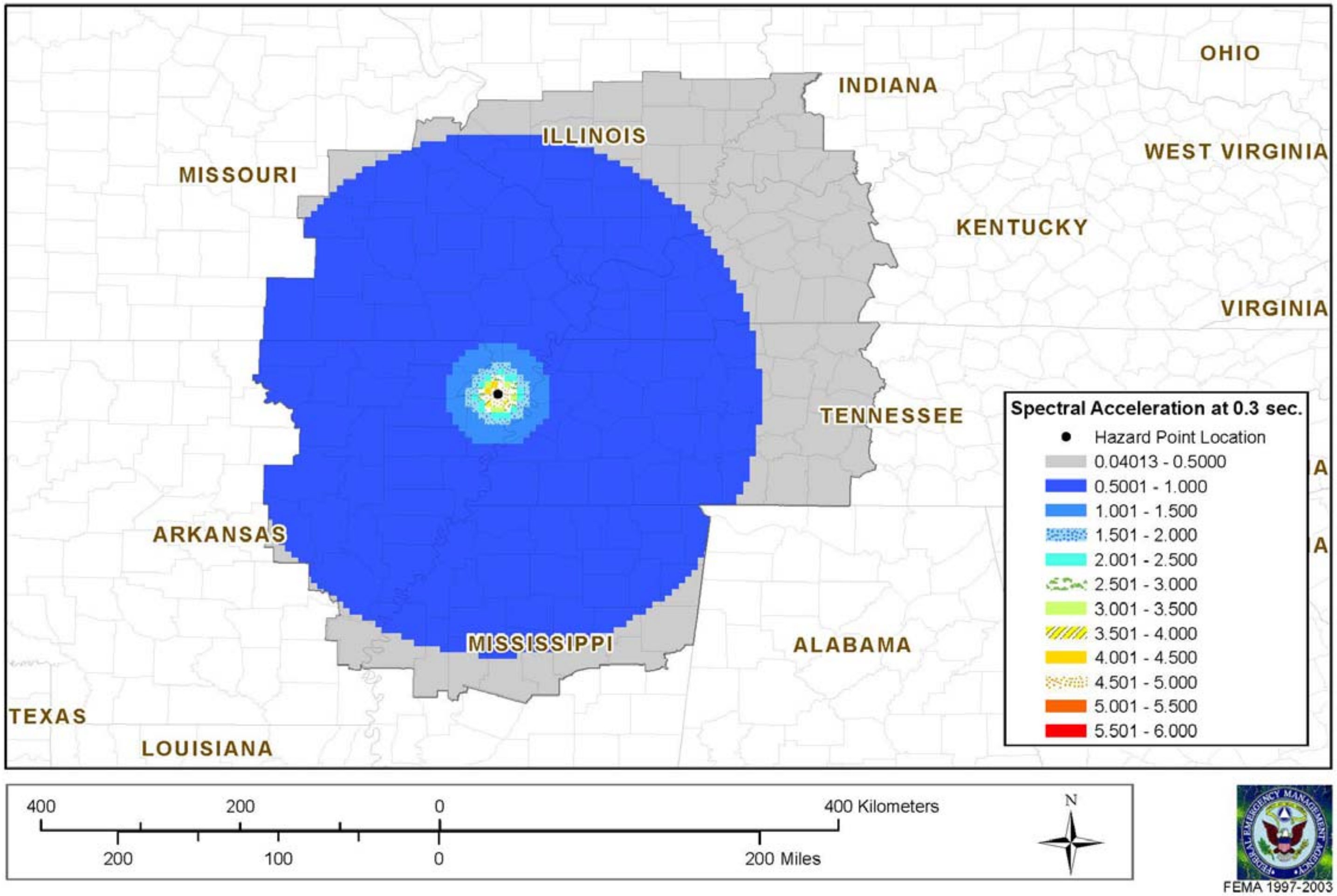


Spectral Acceleration at 1.0 sec.
Study Region: CC A 4026 77 10 H
Hazard Scenario: 16 December 1811 Point Location, M7.7

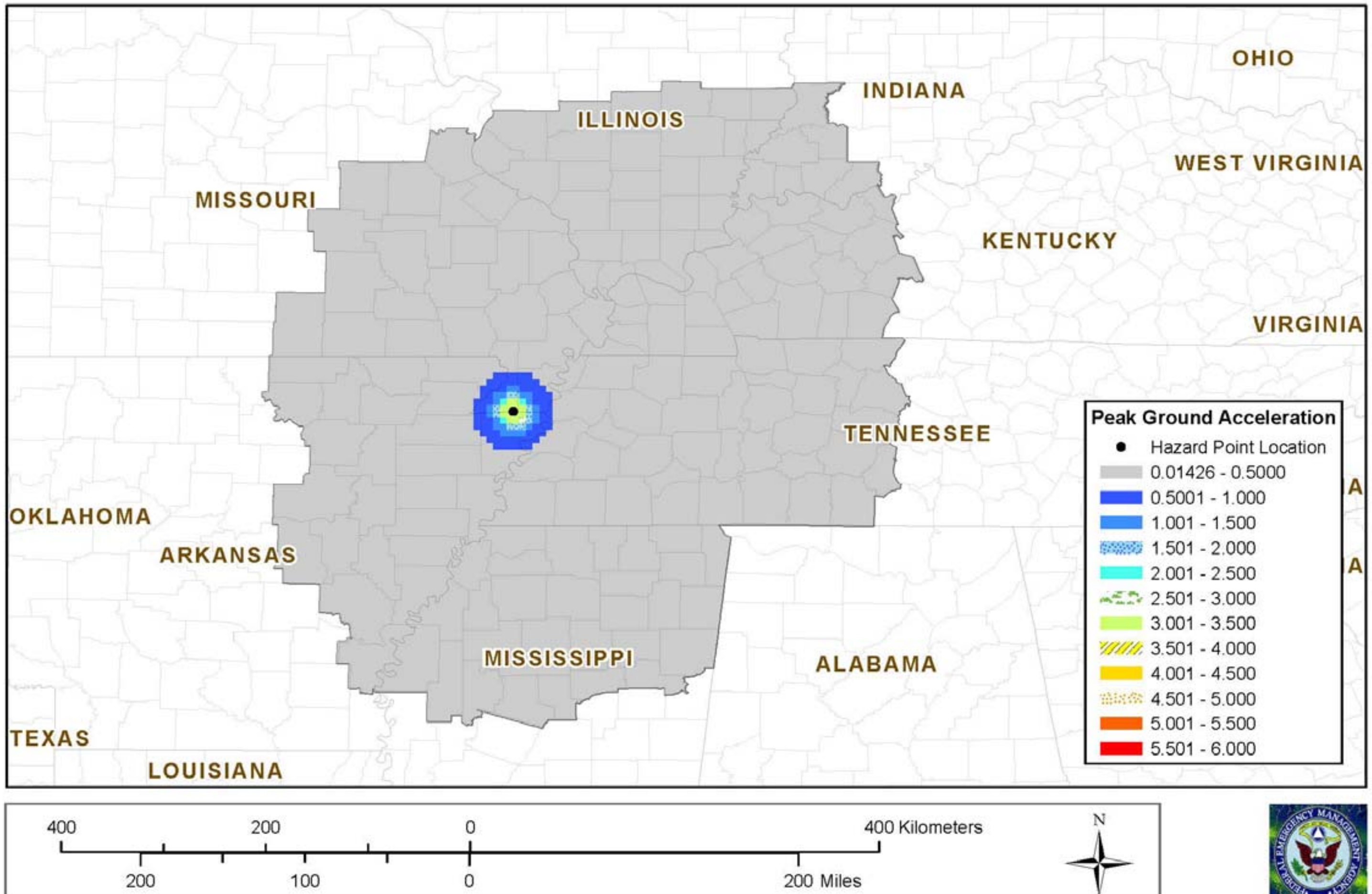


FEMA 1997-2003

Spectral Acceleration at 0.3 sec.
Study Region: CC A 4026 77 10 H
Hazard Scenario: 16 December 1811 Point Location, M7.7

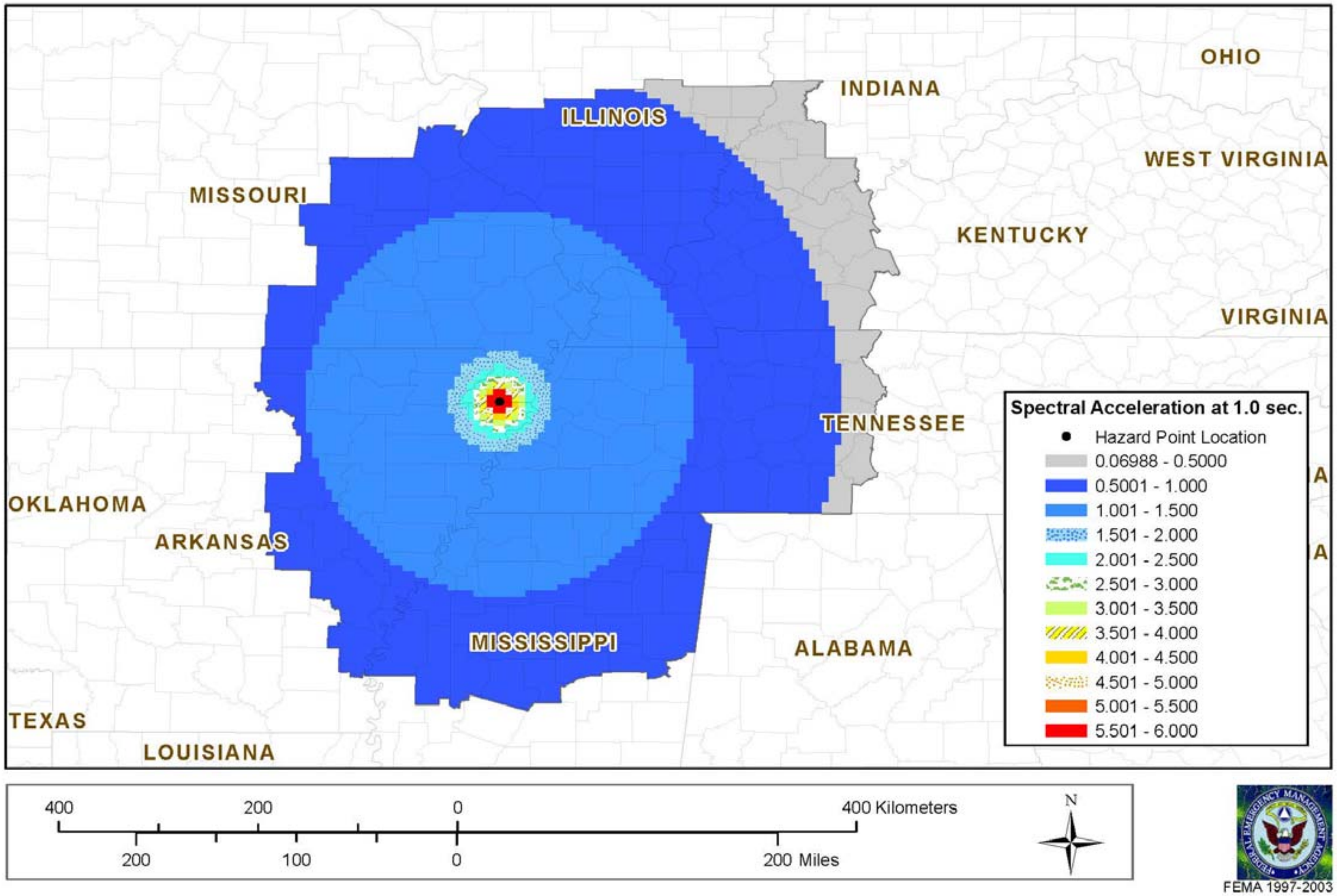


Peak Ground Acceleration
Study Region: CC A 4026 82 10 H
Hazard Scenario: 16 December 1811 Point Location, M8.2

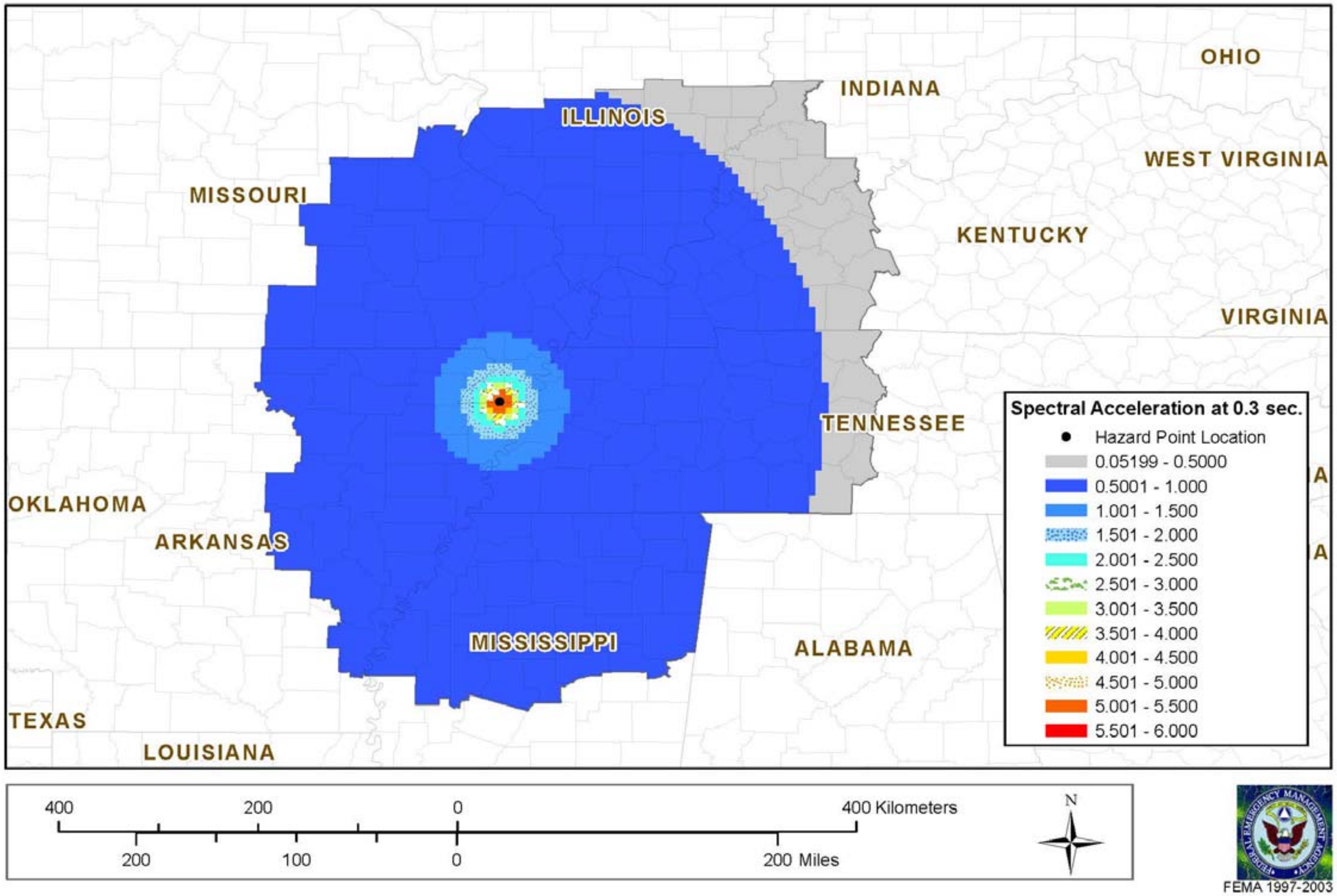


FEMA 1997-2003

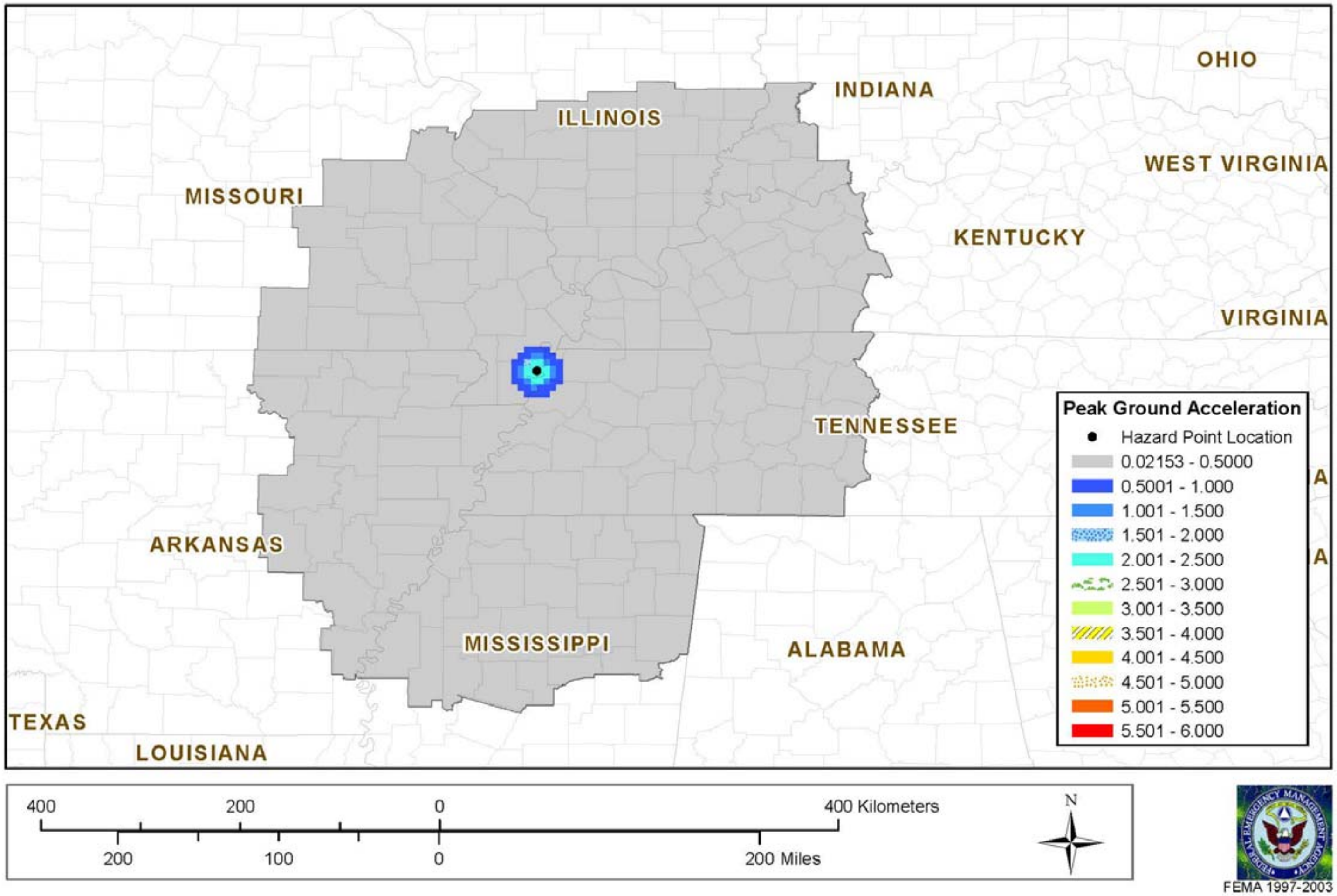
Spectral Acceleration at 1.0 sec.
Study Region: CC A 4026 82 10 H
Hazard Scenario: 16 December 1811 Point Location, M8.2



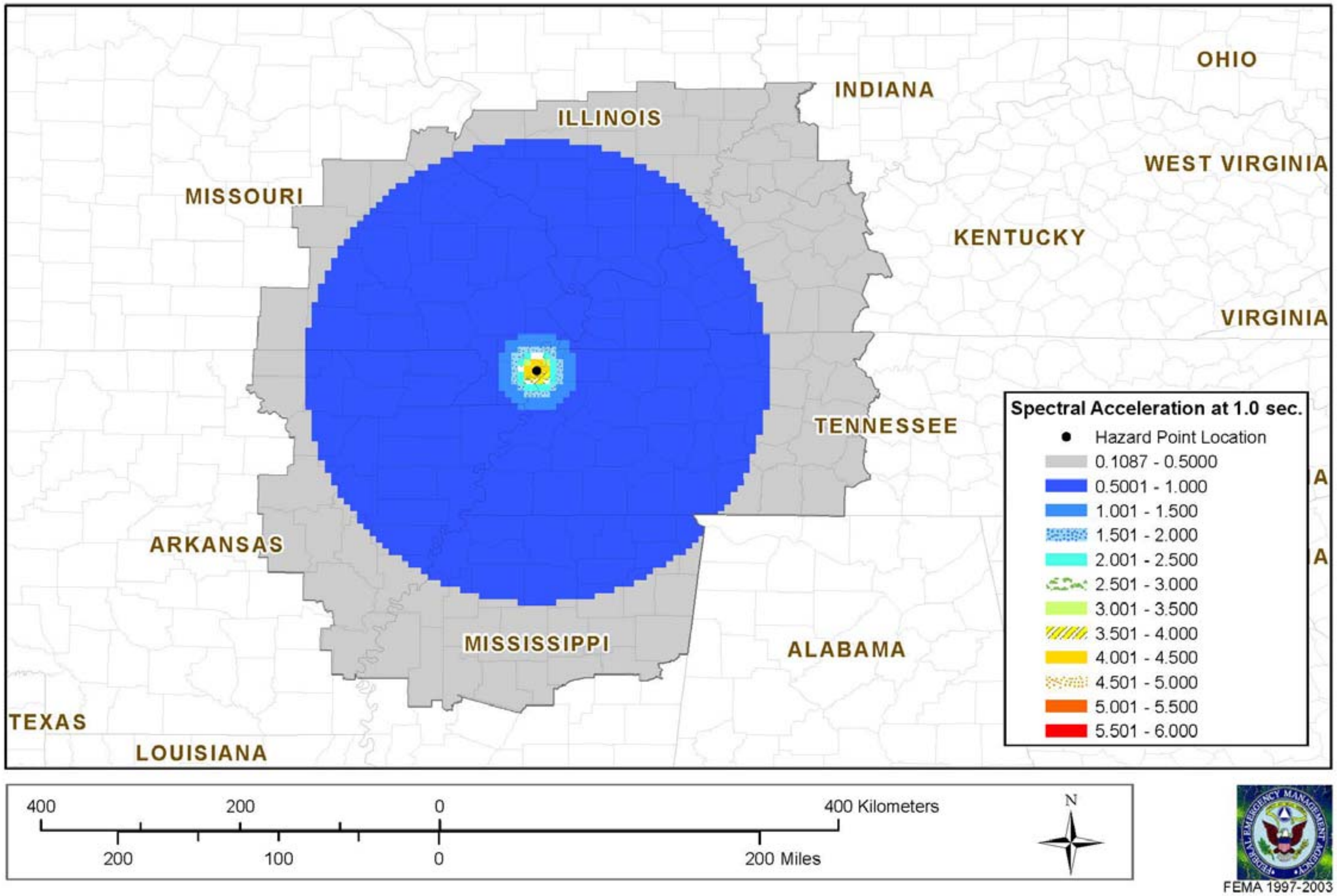
Spectral Acceleration at 0.3 sec.
Study Region: CC A 4026 82 10 H
Hazard Scenario: 16 December 1811 Point Location, M8.2



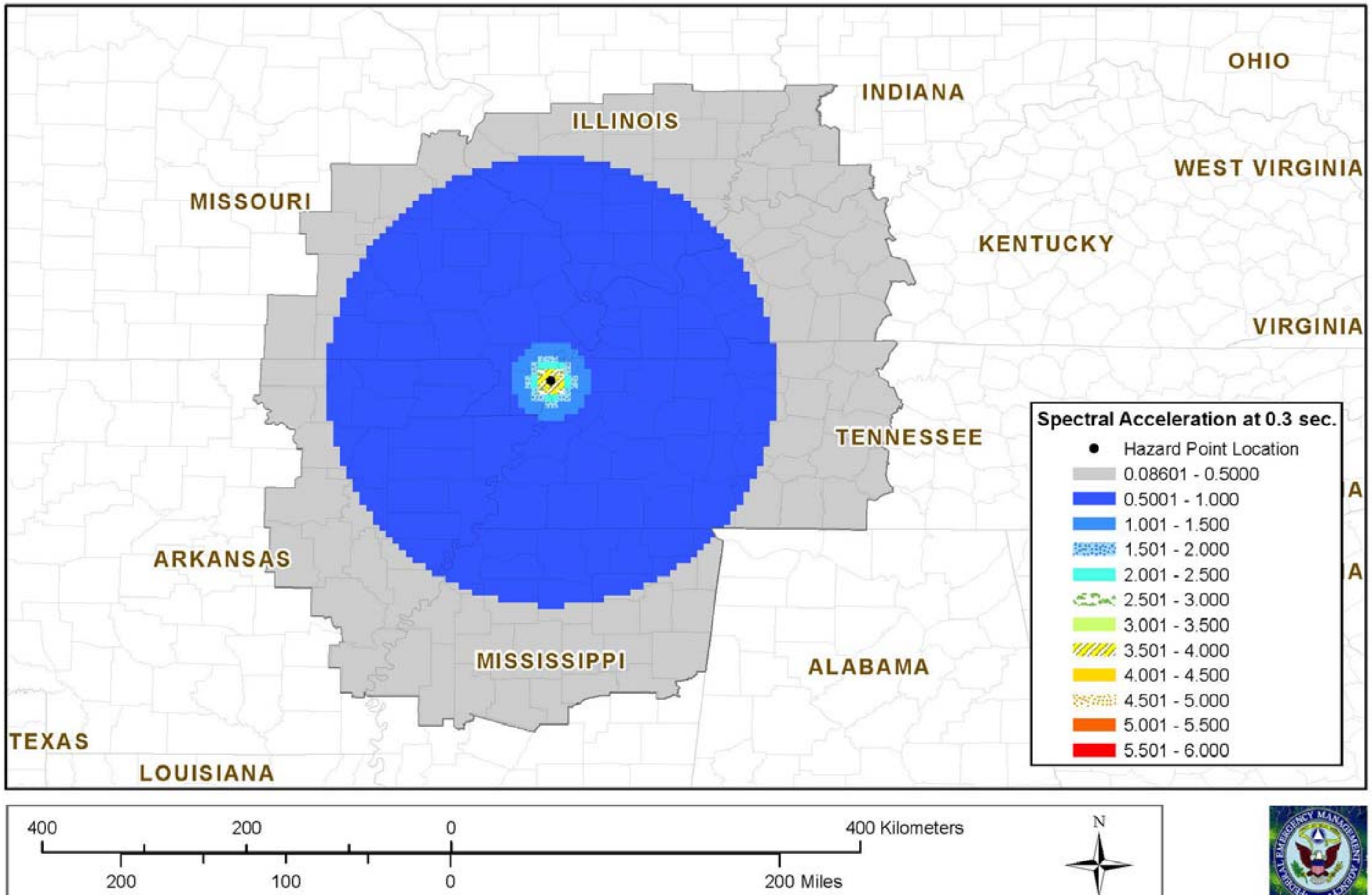
Peak Ground Acceleration
Study Region: CC A 4027 71 10 H
Hazard Scenario: 23 January 1812 Point Location, M7.1



Spectral Acceleration at 1.0 sec.
Study Region: CC A 4027 71 10 H
Hazard Scenario: 23 January 1812 Point Location, M7.1

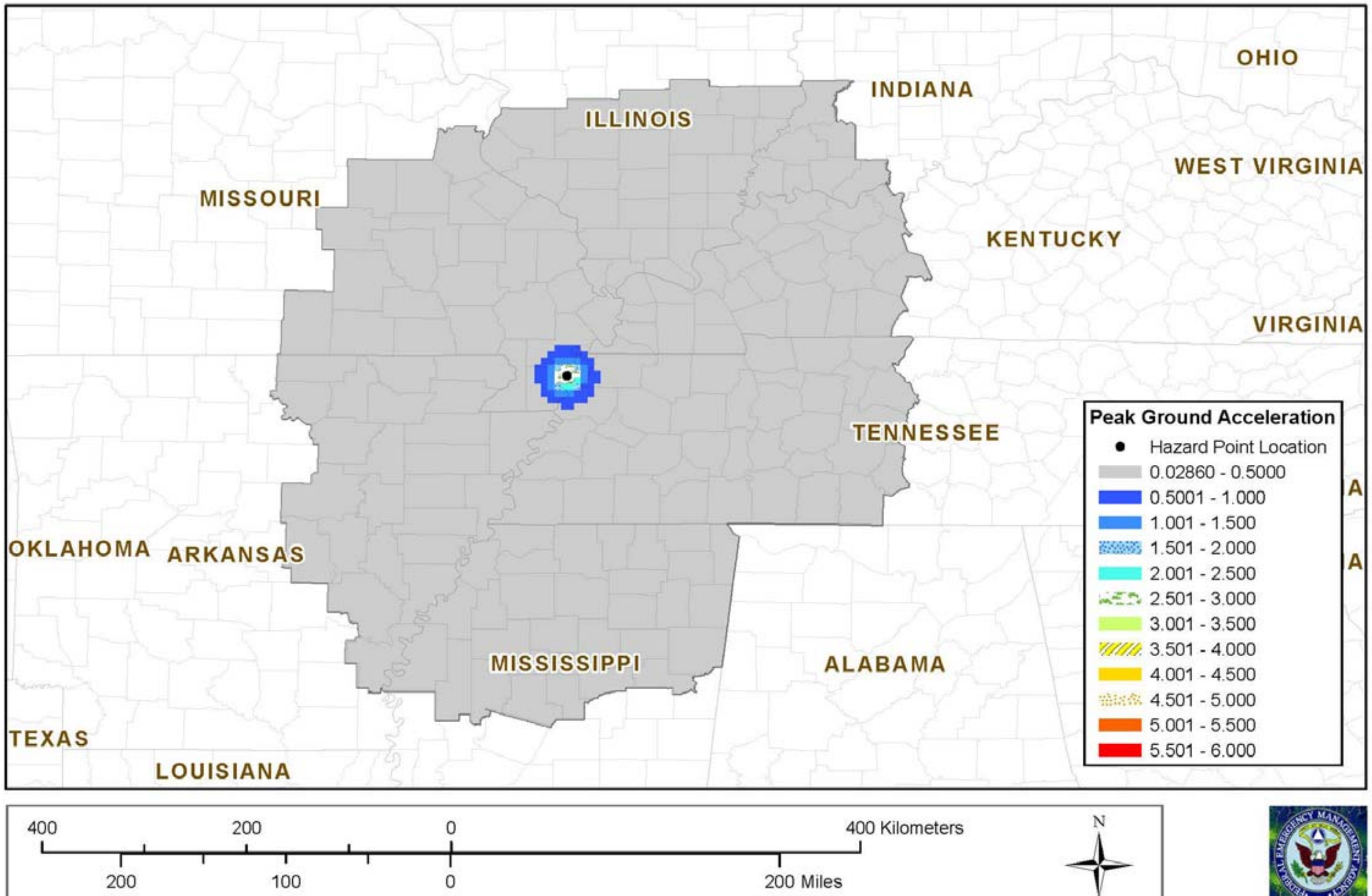


Spectral Acceleration at 0.3 sec.
Study Region: CC A 4027 71 10 H
Hazard Scenario: 23 January 1812 Point Location, M7.1



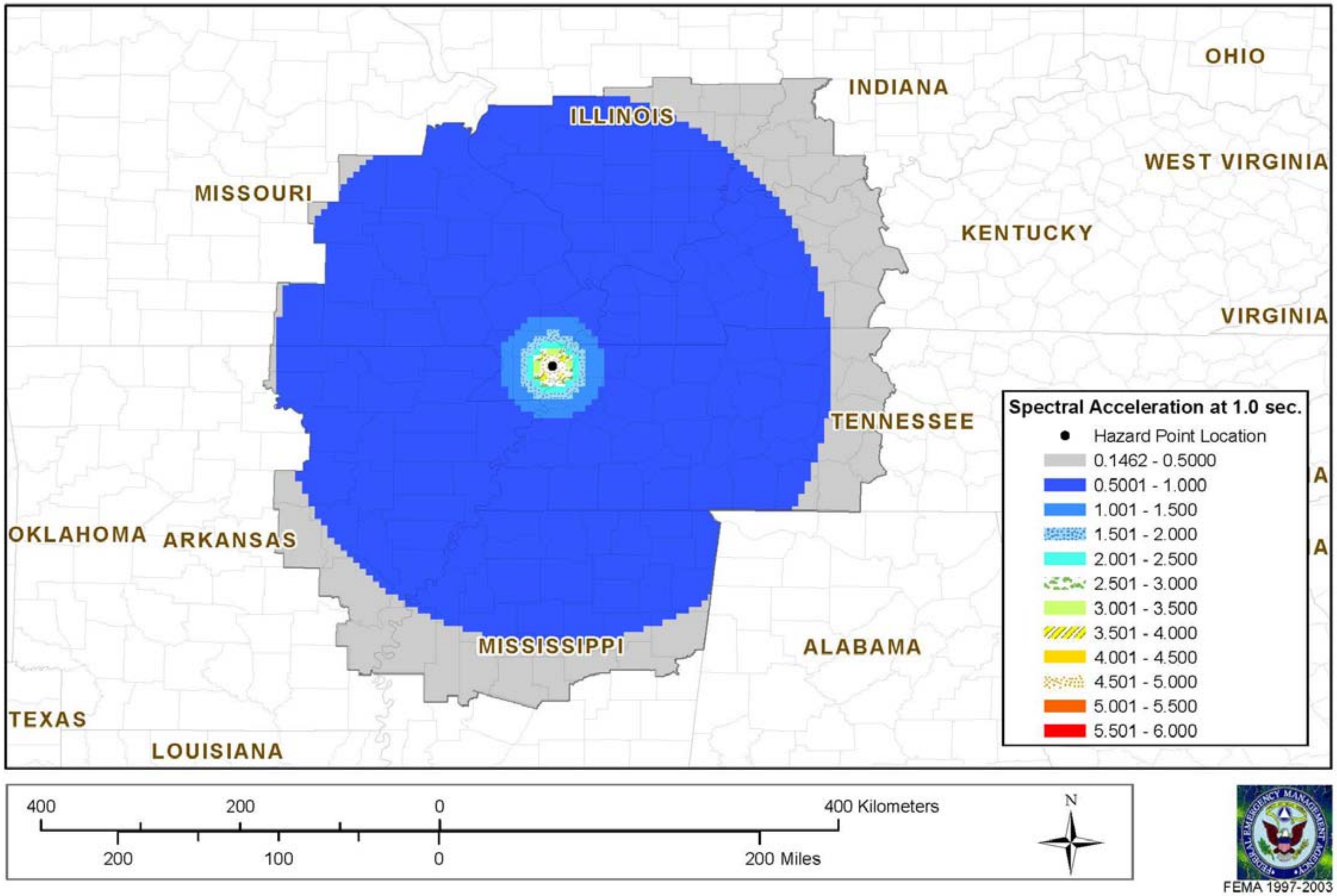
FEMA 1997-2003

Peak Ground Acceleration
Study Region: CC A 4027 75 10 H
Hazard Scenario: 23 January 1812 Point Location, M7.5

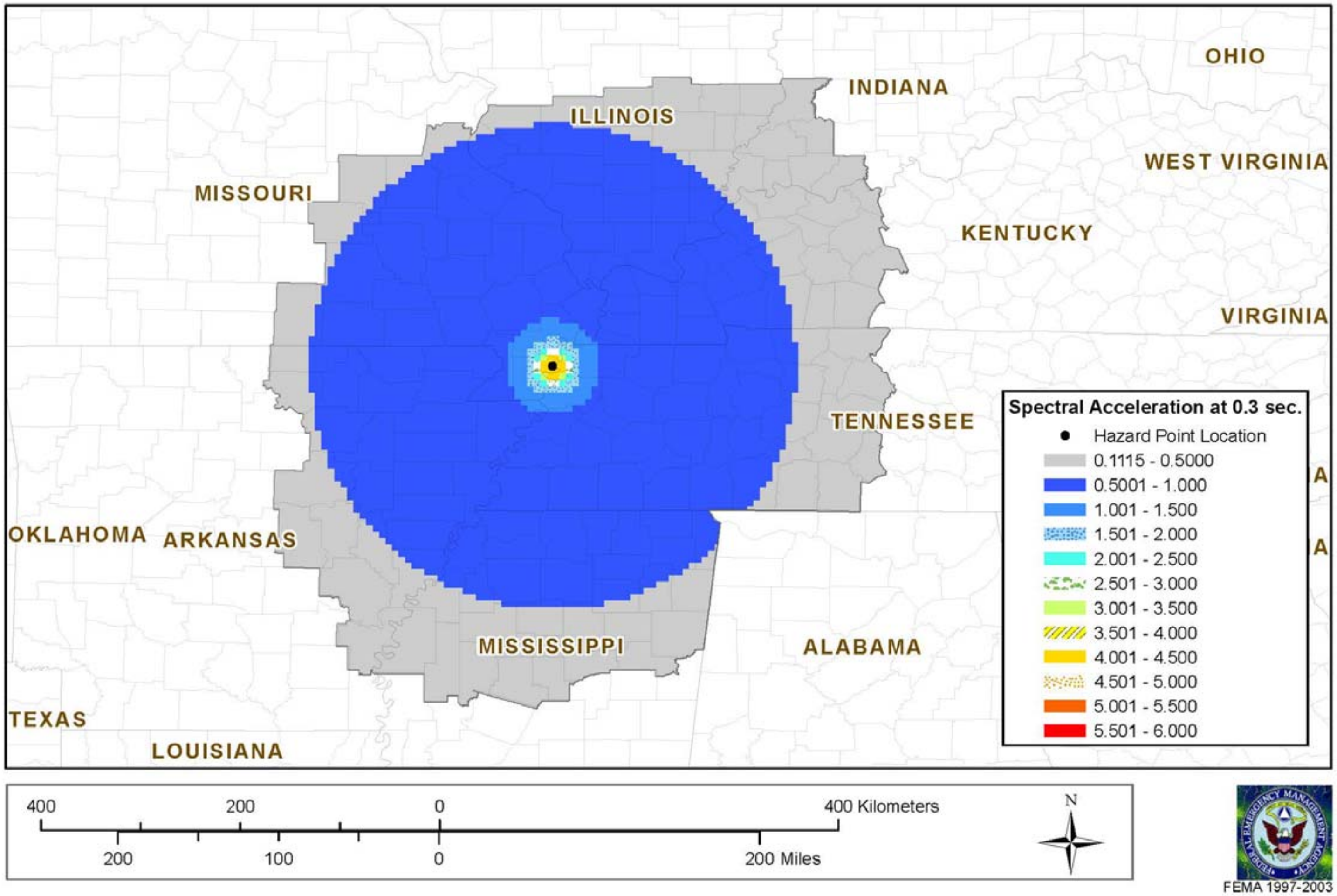


FEMA 1997-2003

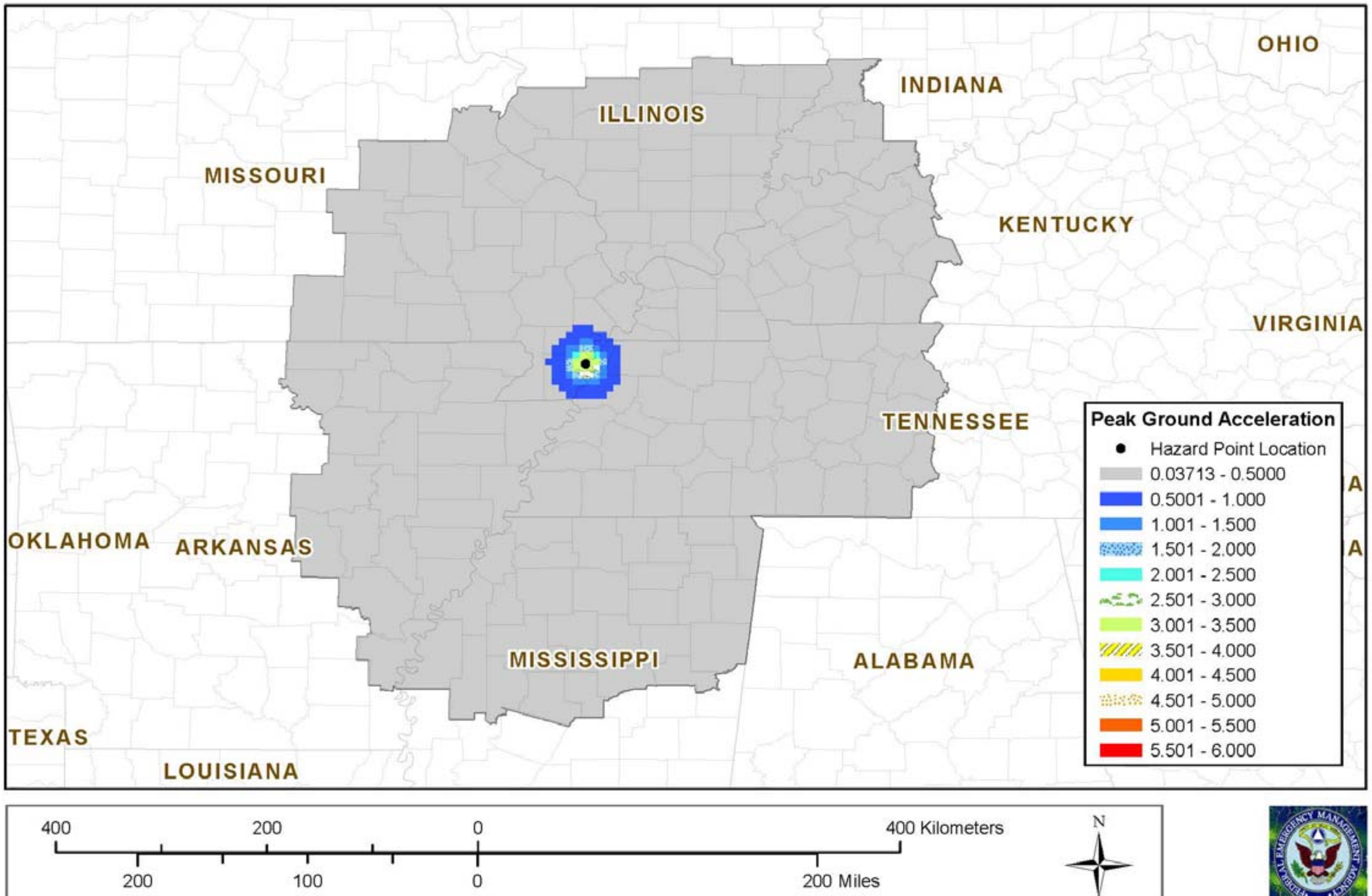
Spectral Acceleration at 1.0 sec.
Study Region: CC A 4027 75 10 H
Hazard Scenario: 23 January 1812 Point Location, M7.5



Spectral Acceleration at 0.3 sec.
Study Region: CC A 4027 75 10 H
Hazard Scenario: 23 January 1812 Point Location, M7.5

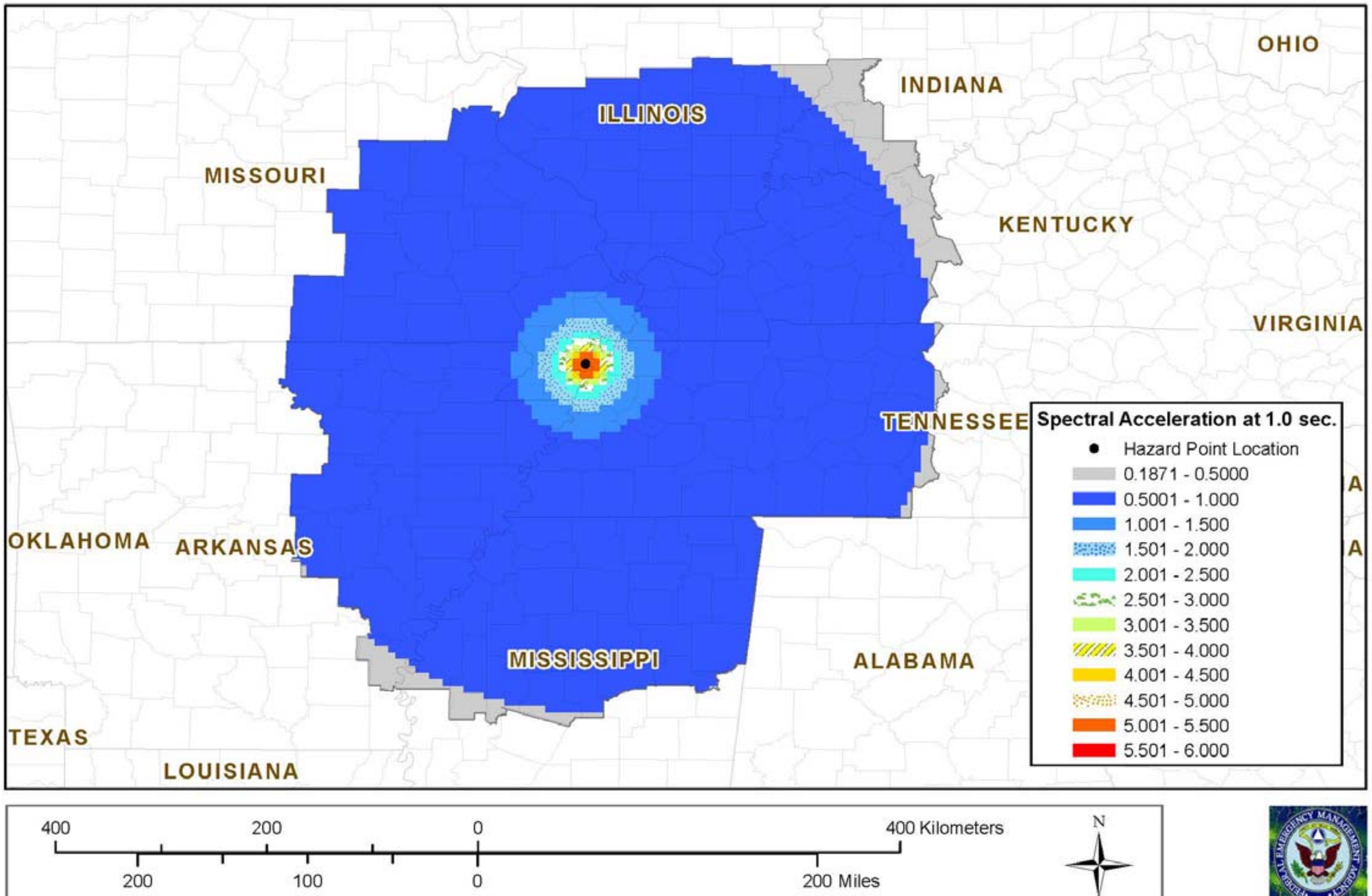


Peak Ground Acceleration
Study Region: CC A 4027 79 10 H
Hazard Scenario: 23 January 1812 Point Location, M7.9



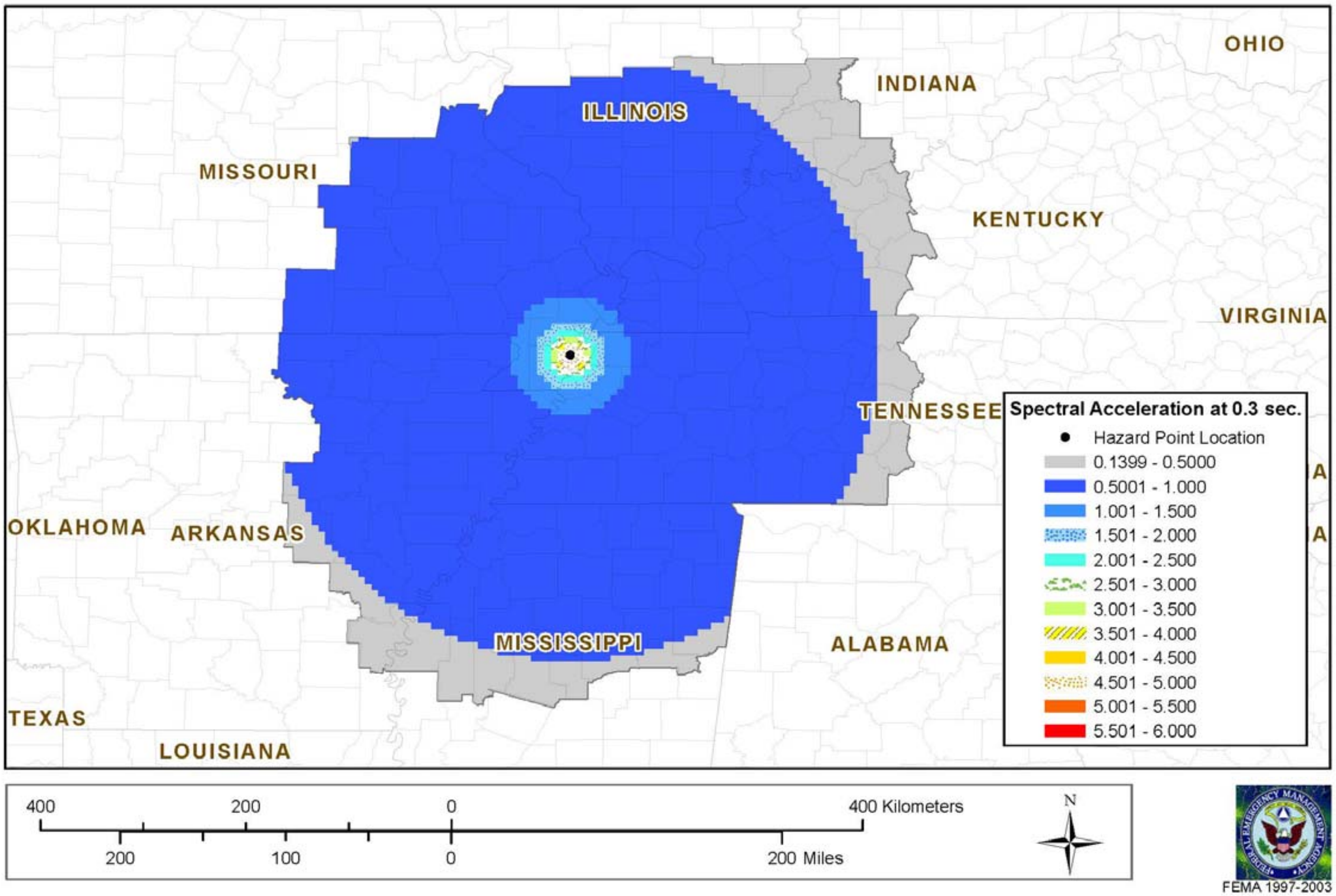
FEMA 1997-2003

Spectral Acceleration at 1.0 sec.
Study Region: CC A 4027 79 10 H
Hazard Scenario: 23 January 1812 Point Location, M7.9

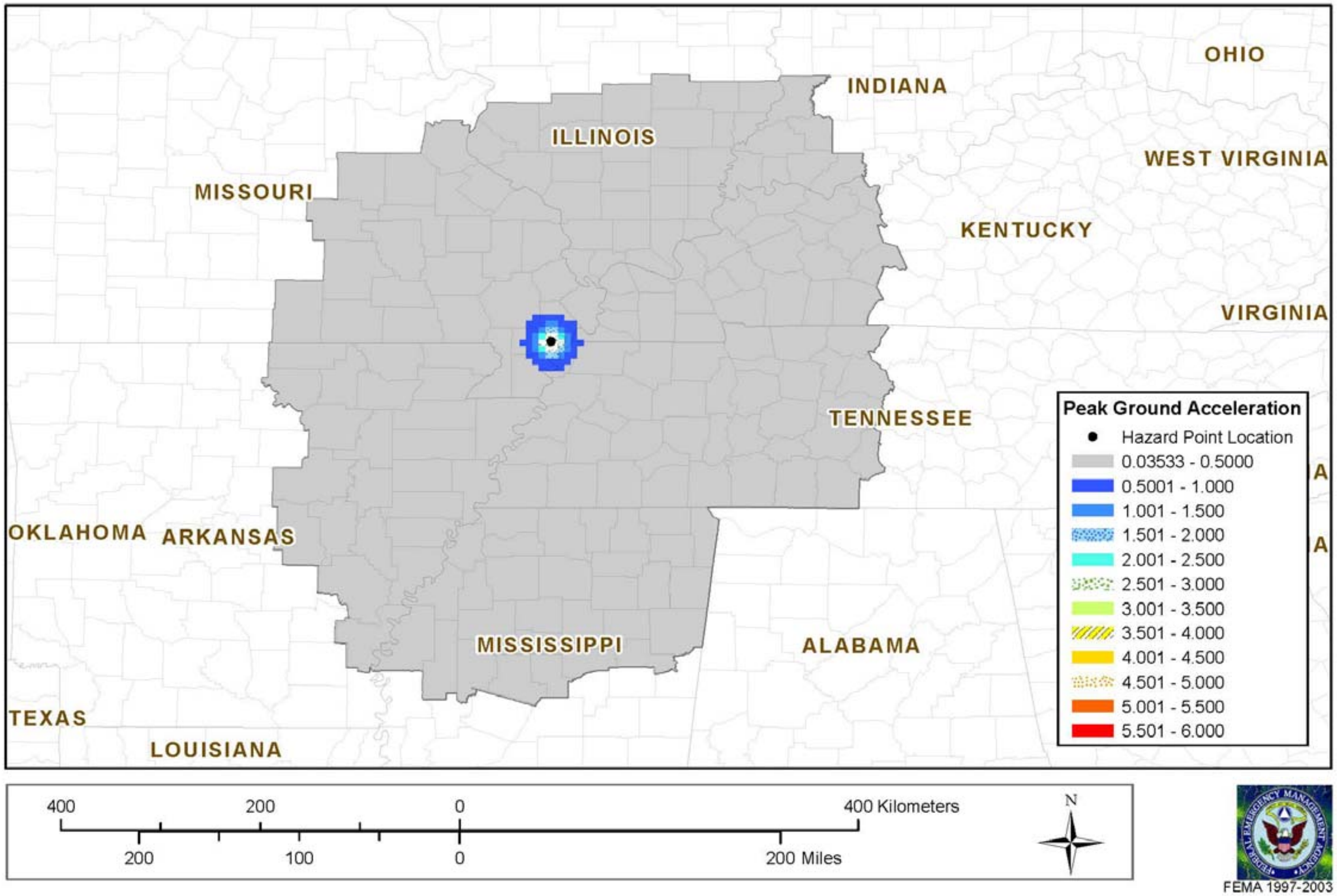


FEMA 1997-2003

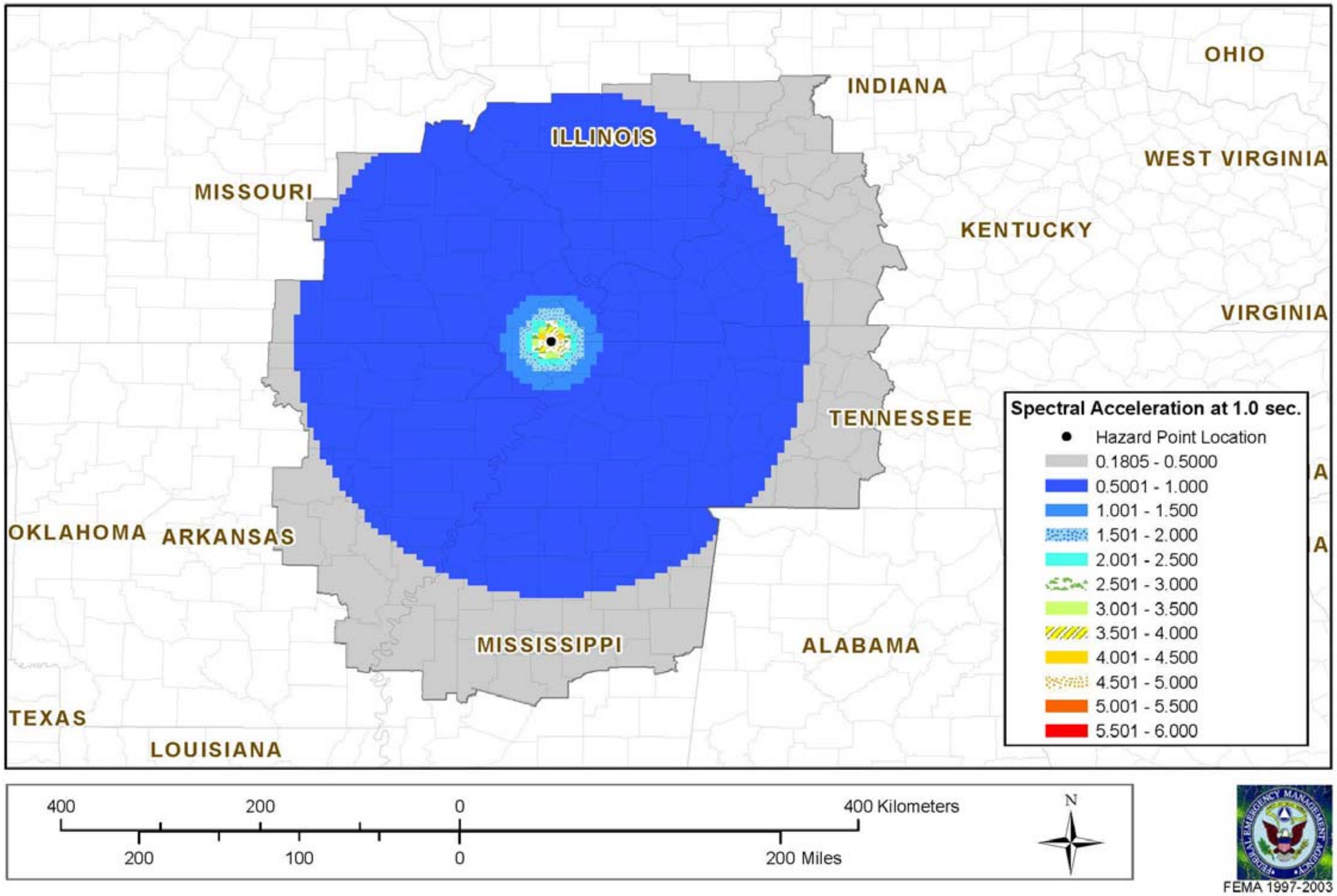
Spectral Acceleration at 0.3 sec.
Study Region: CC A 4027 79 10 H
Hazard Scenario: 23 January 1812 Point Location, M7.9



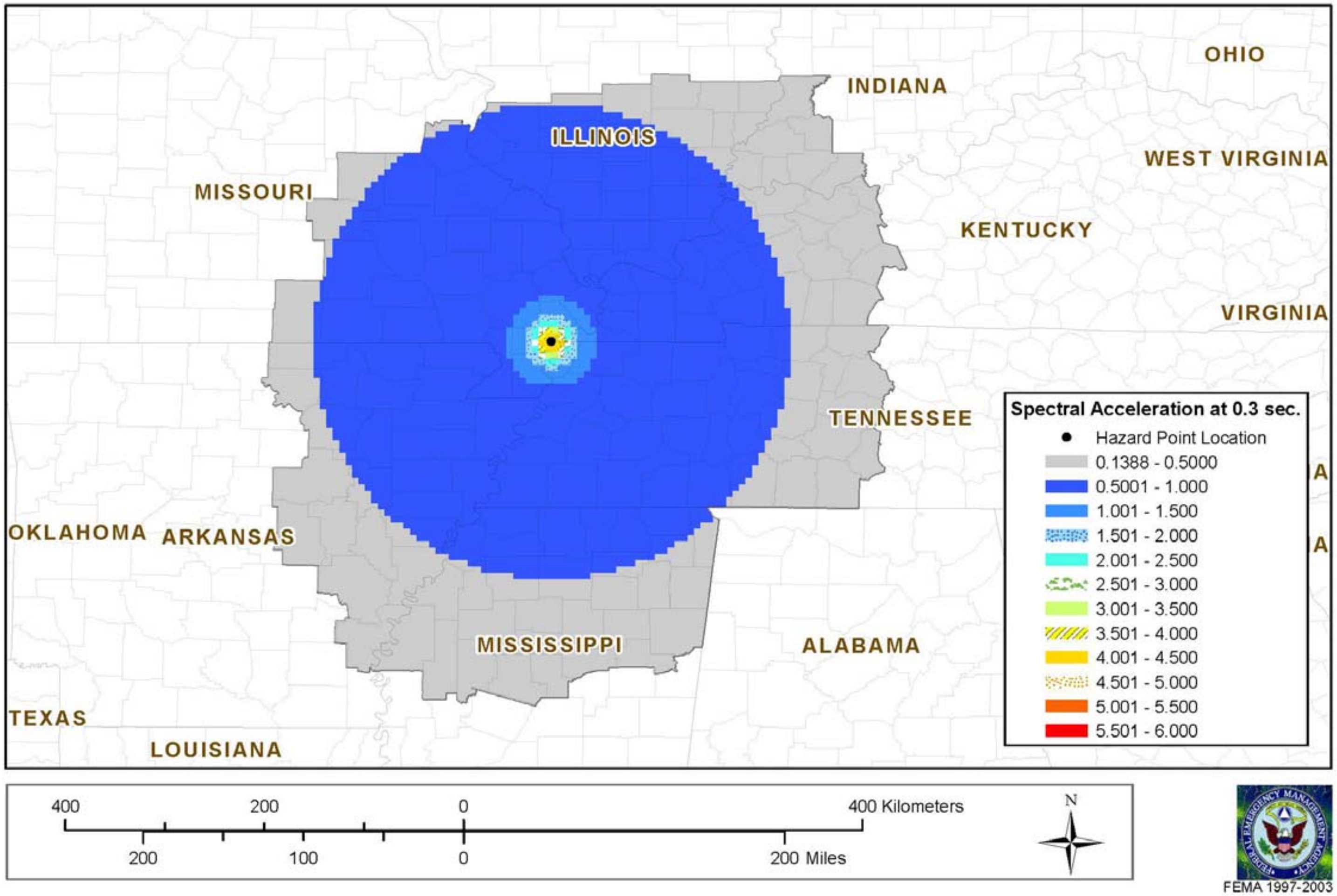
Peak Ground Acceleration
Study Region: CC A 4028 74 10 H
Hazard Scenario: 7 February 1812 Point Location, M7.4



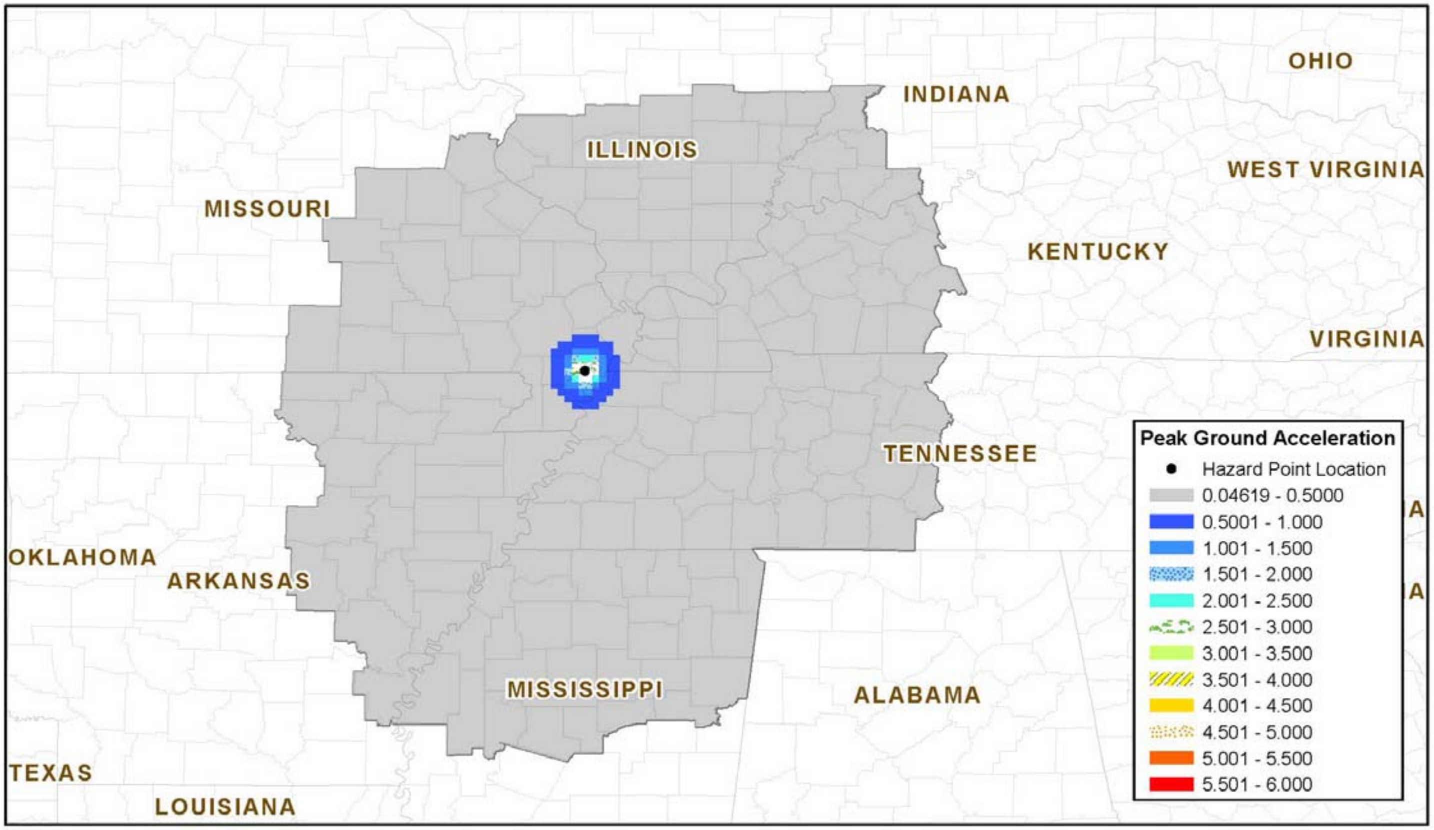
Spectral Acceleration at 1.0 sec.
Study Region: CC A 4028 74 10 H
Hazard Scenario: 7 February 1812 Point Location, M7.4

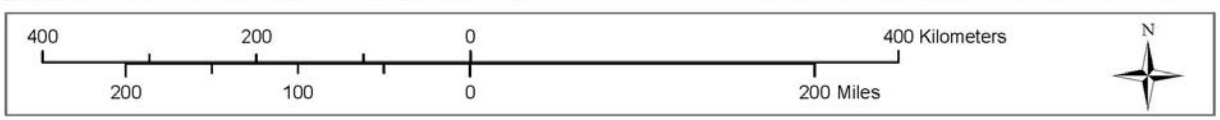


Spectral Acceleration at 0.3 sec.
Study Region: CC A 4028 74 10 H
Hazard Scenario: 7 February 1812 Point Location, M7.4



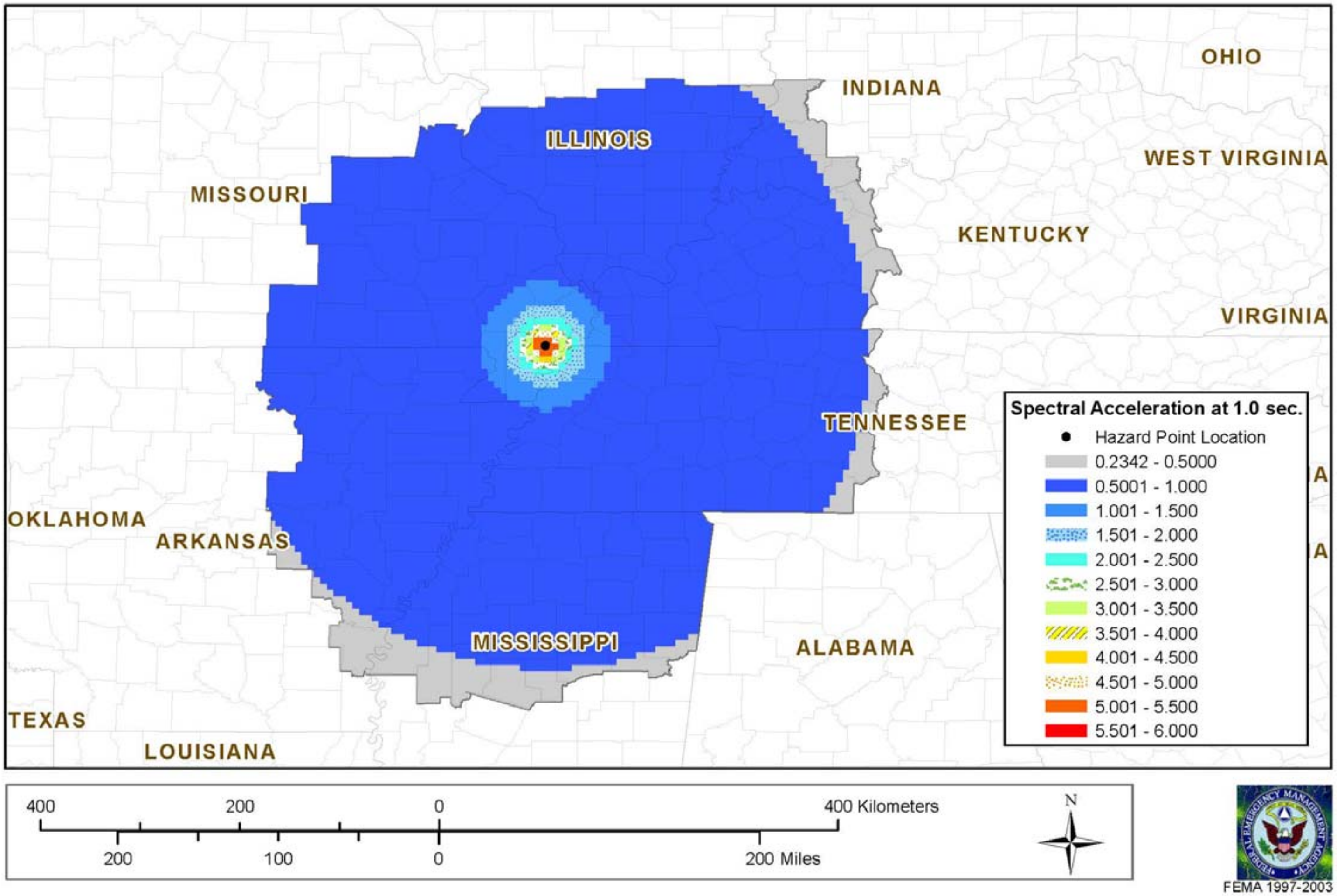
Peak Ground Acceleration
Study Region: CC A 4028 78 10 H
Hazard Scenario: 7 February 1812 Point Location, M7.8



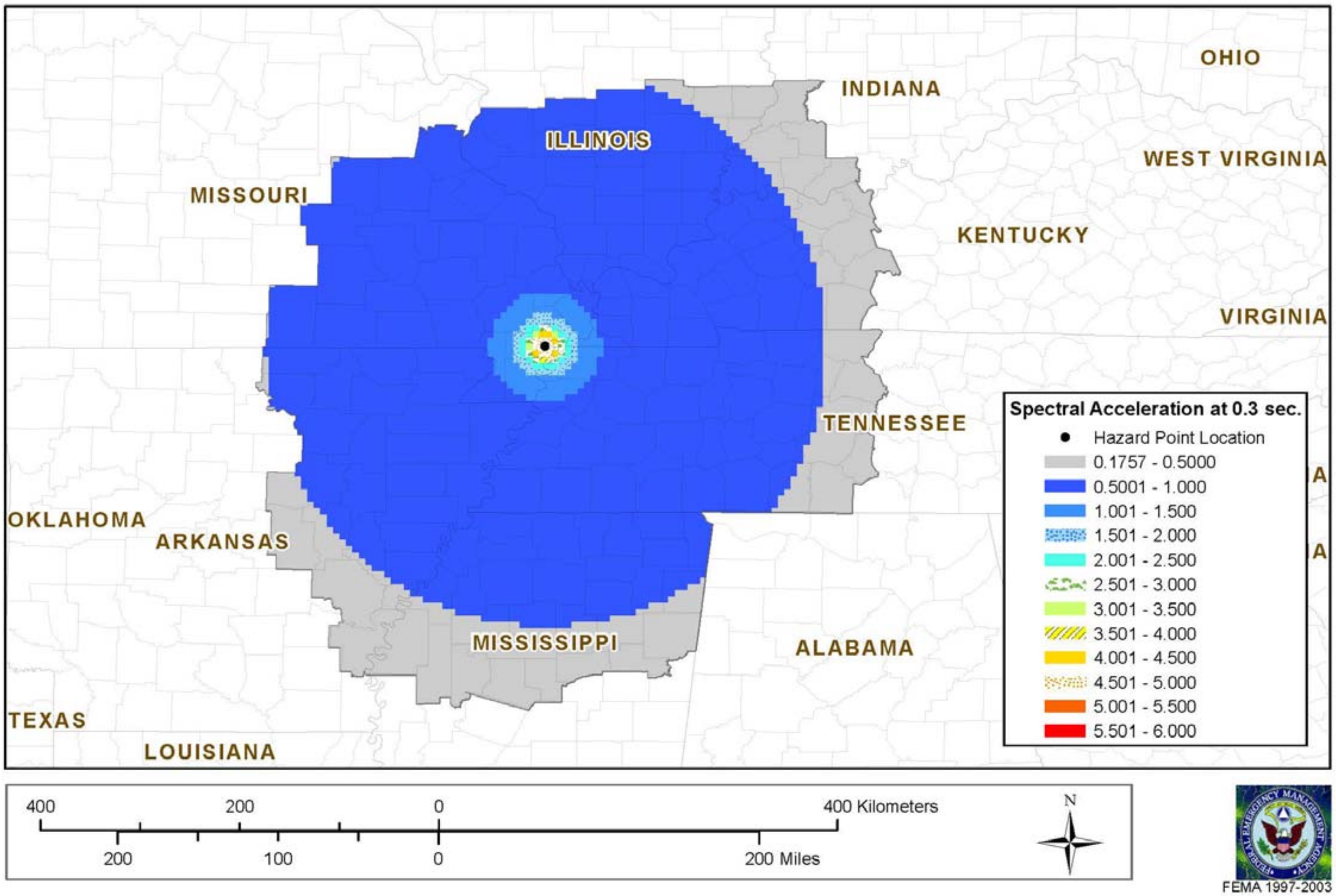


FEMA 1997-2003

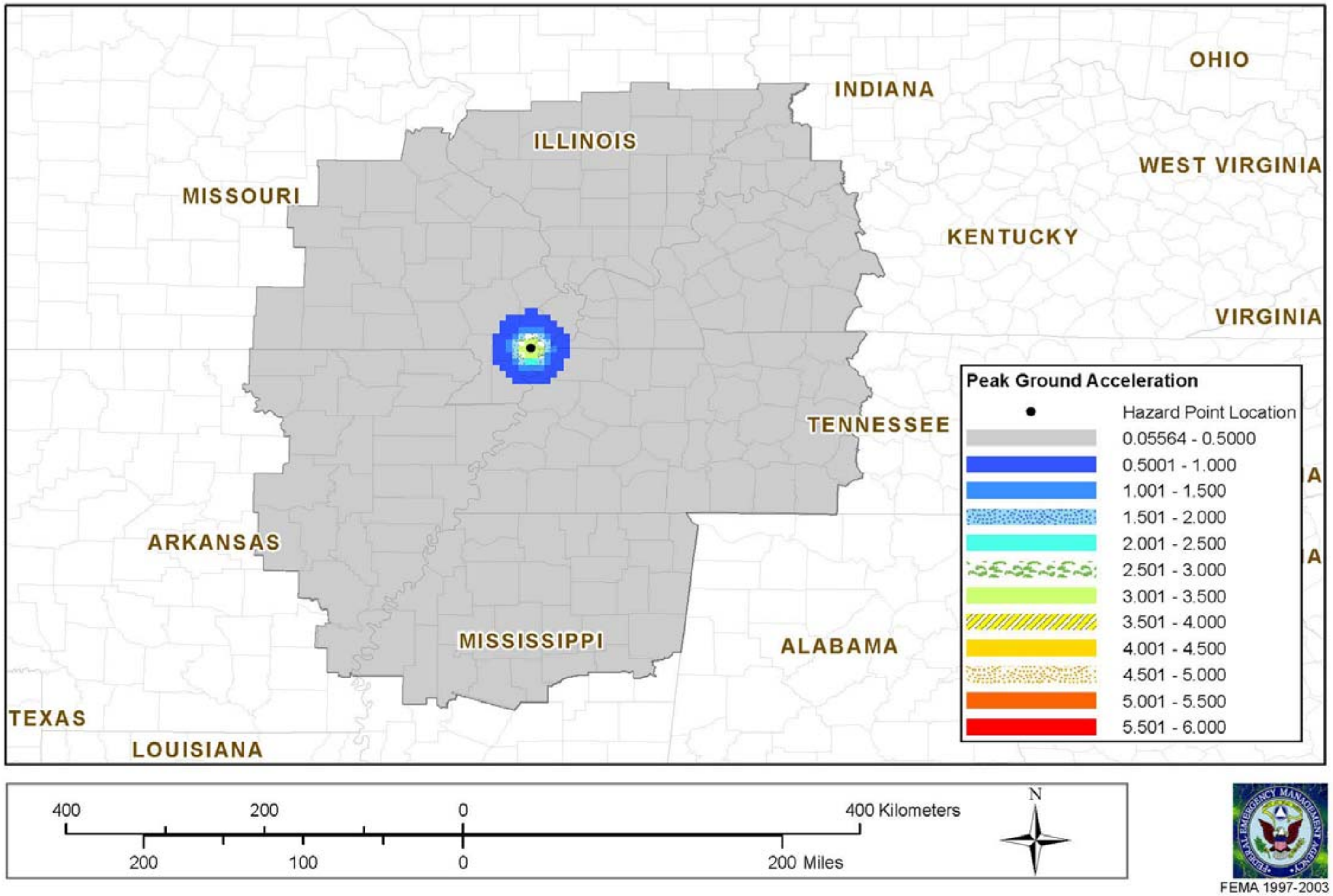
Spectral Acceleration at 1.0 sec.
Study Region: CC A 4028 78 10 H
Hazard Scenario: 7 February 1812 Point Location, M7.8



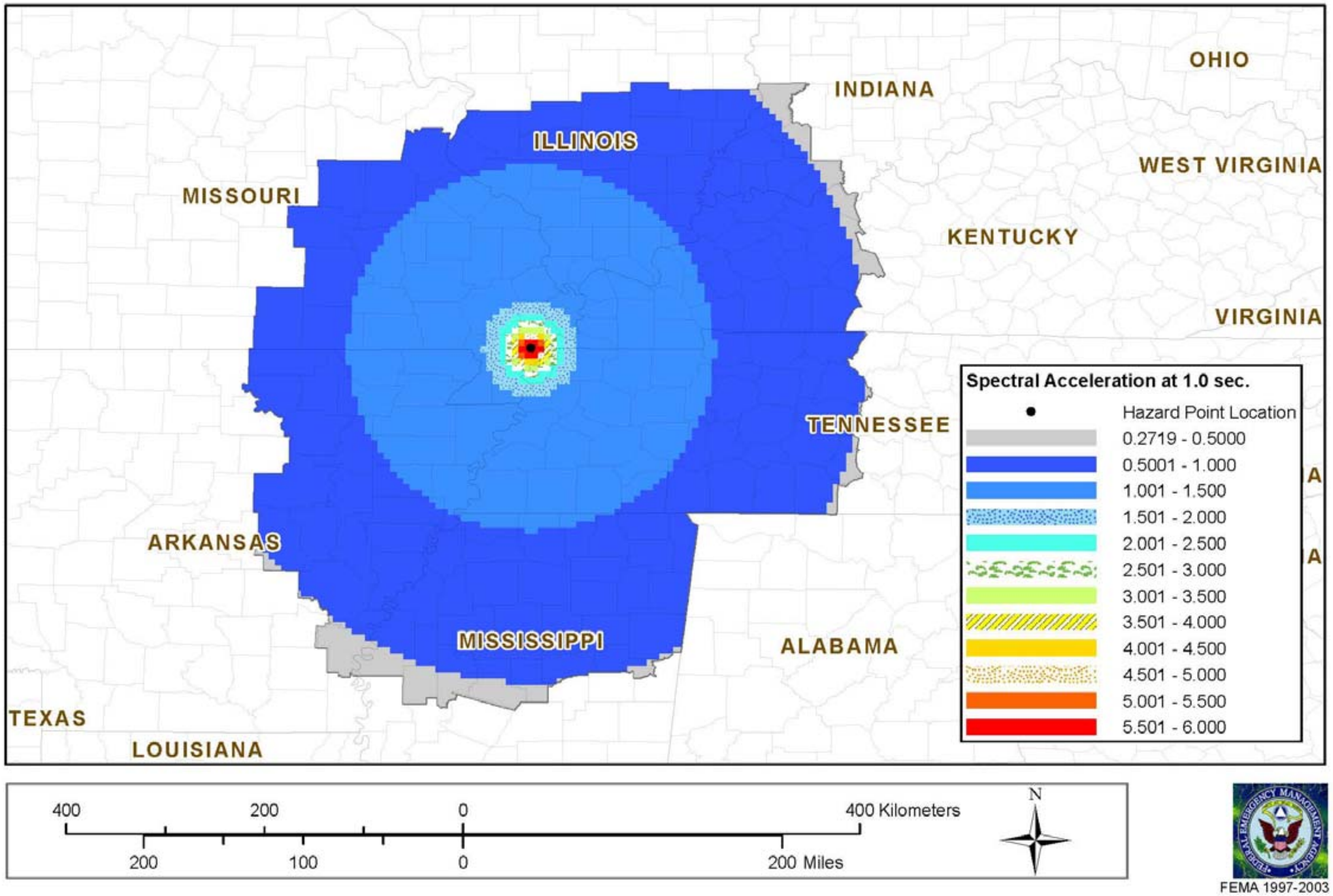
Spectral Acceleration at 0.3 sec.
Study Region: CC A 4028 78 10 H
Hazard Scenario: 7 February 1812 Point Location, M7.8



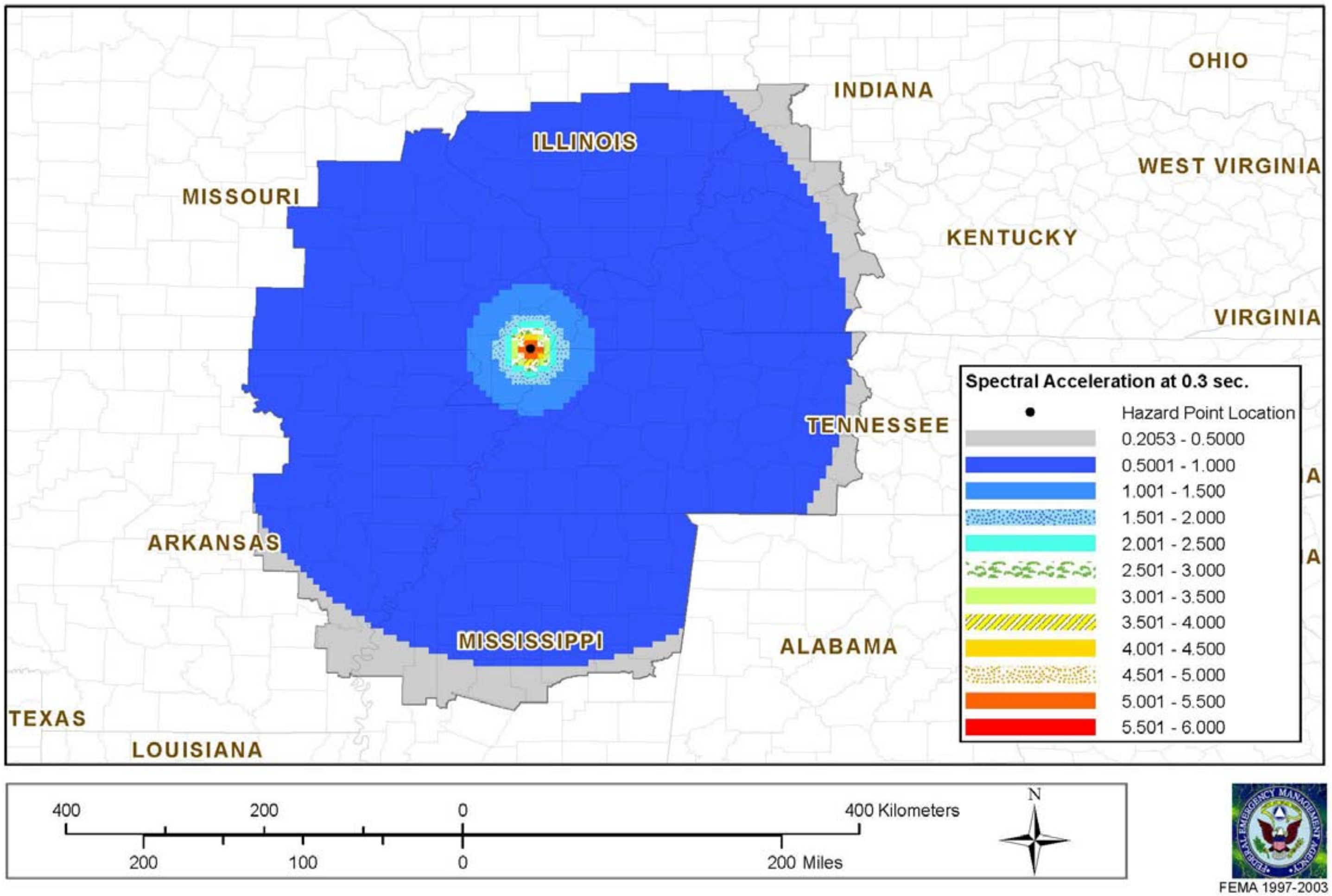
Peak Ground Acceleration
Study Region: CC A 4028 81 10 H
Hazard Scenario: 7 February 1812 Point Location, M8.1



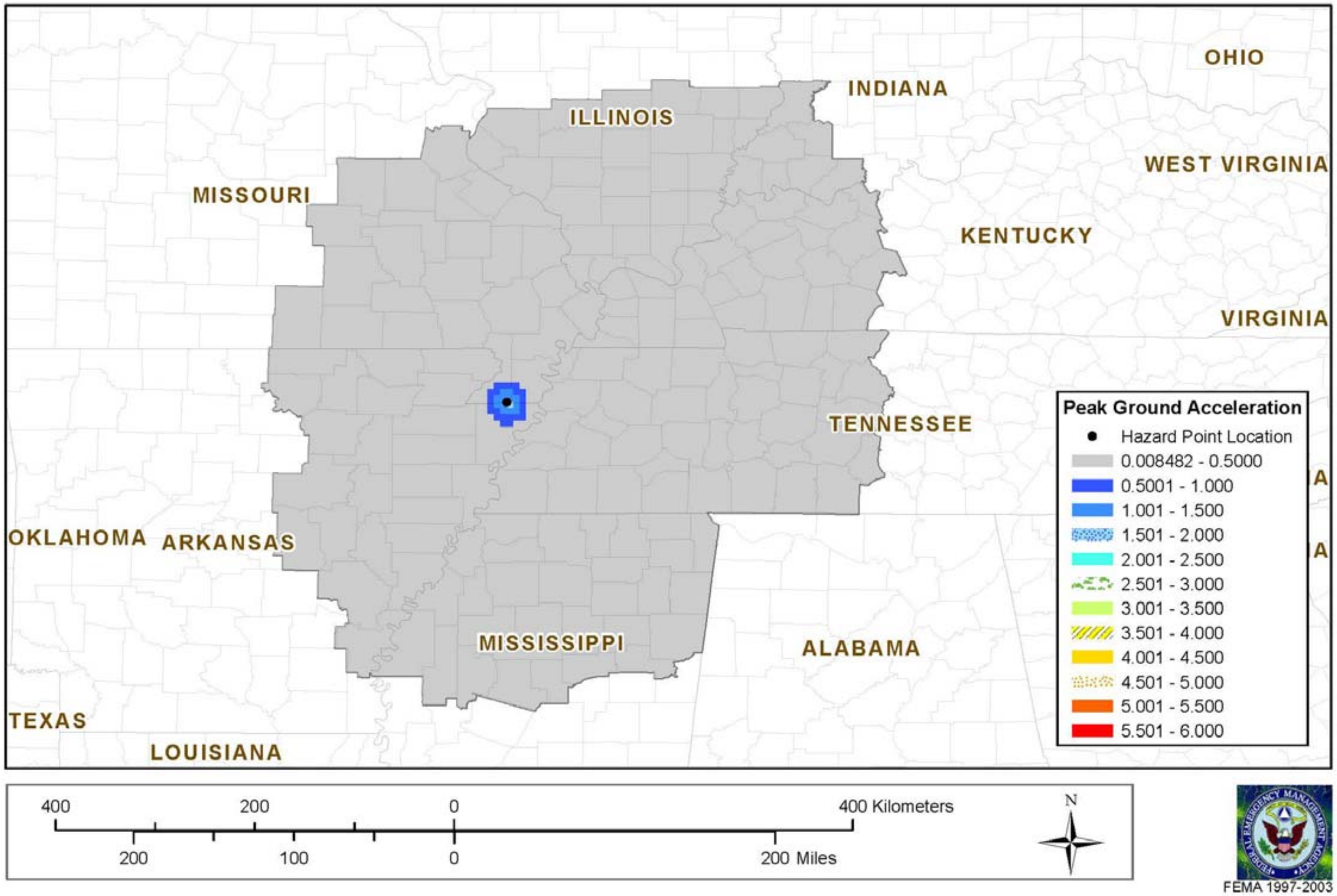
Spectral Acceleration at 1.0 sec.
Study Region: CC A 4028 81 10 H
Hazard Scenario: 7 February 1812 Point Location, M8.1



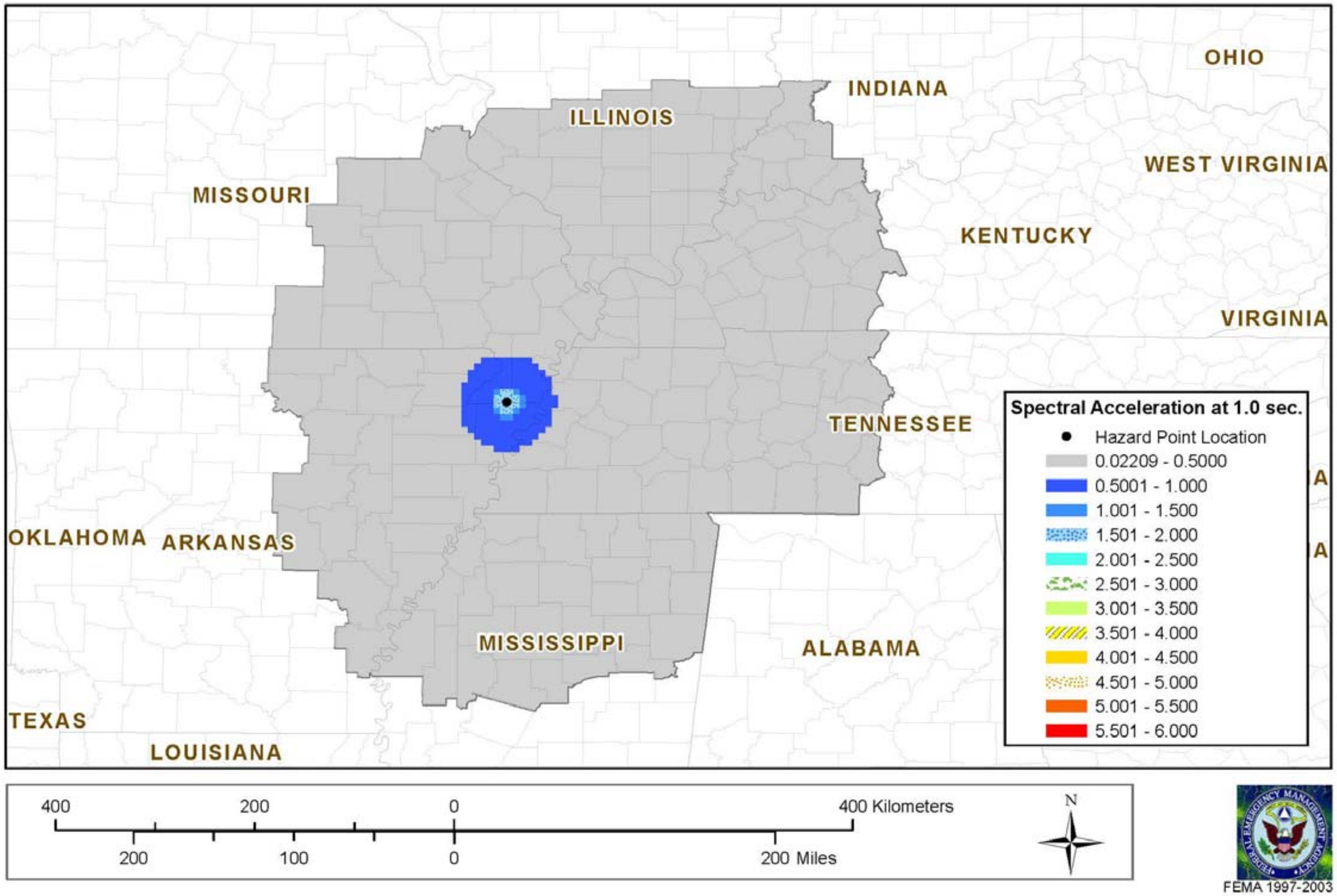
Spectral Acceleration at 0.3 sec.
Study Region: CC A 4028 81 10 H
Hazard Scenario: 7 February 1812 Point Location, M8.1



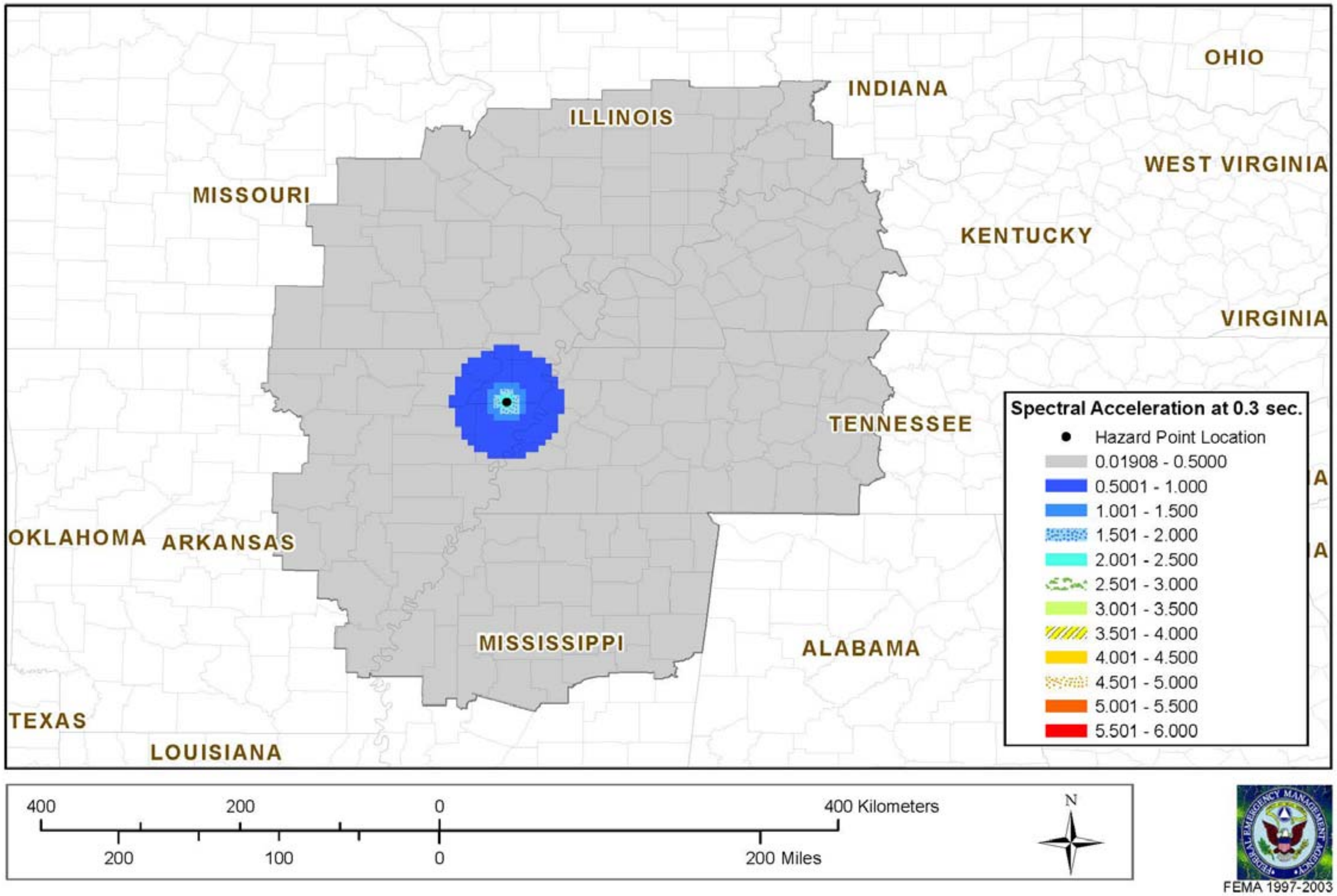
Peak Ground Acceleration
Study Region: CC C 4026 72 10 H
Hazard Scenario: 16 December 1811 Point Location, M7.2



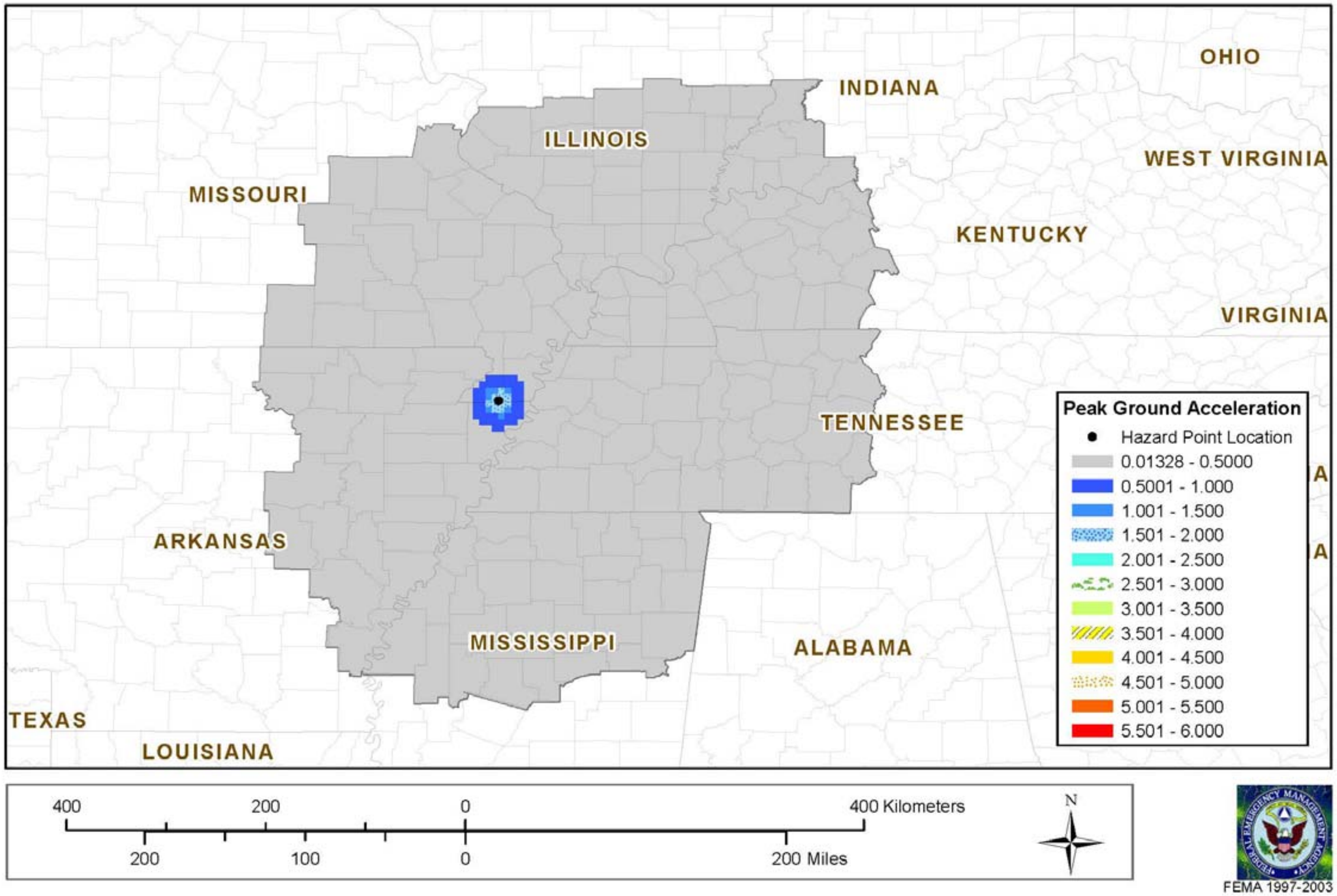
Spectral Acceleration at 1.0 sec.
Study Region: CC C 4026 72 10 H
Hazard Scenario: 16 December 1811 Point Location, M7.2



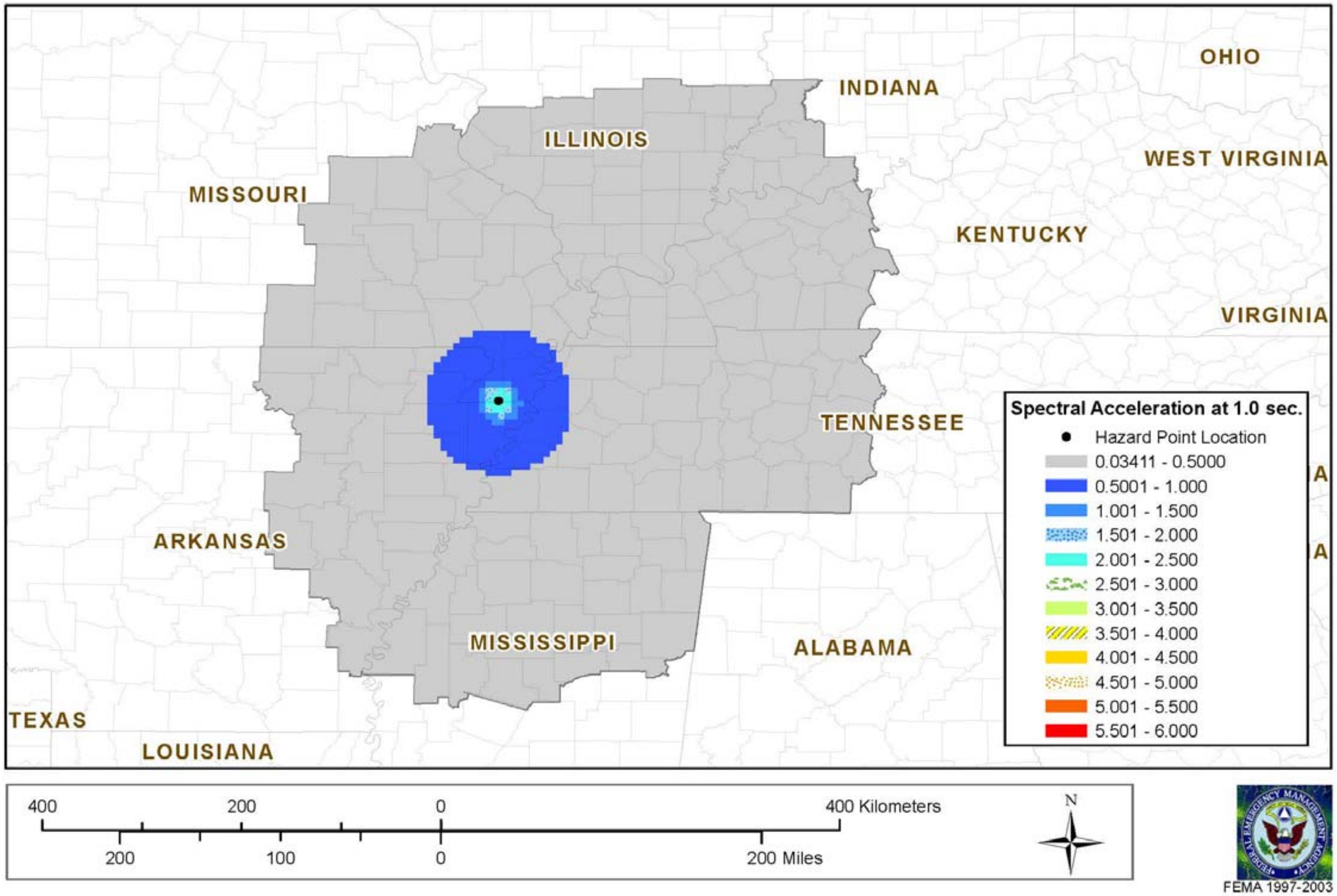
Spectral Acceleration at 0.3 sec.
Study Region: CC C 4026 72 10 H
Hazard Scenario: 16 December 1811 Point Location, M7.2



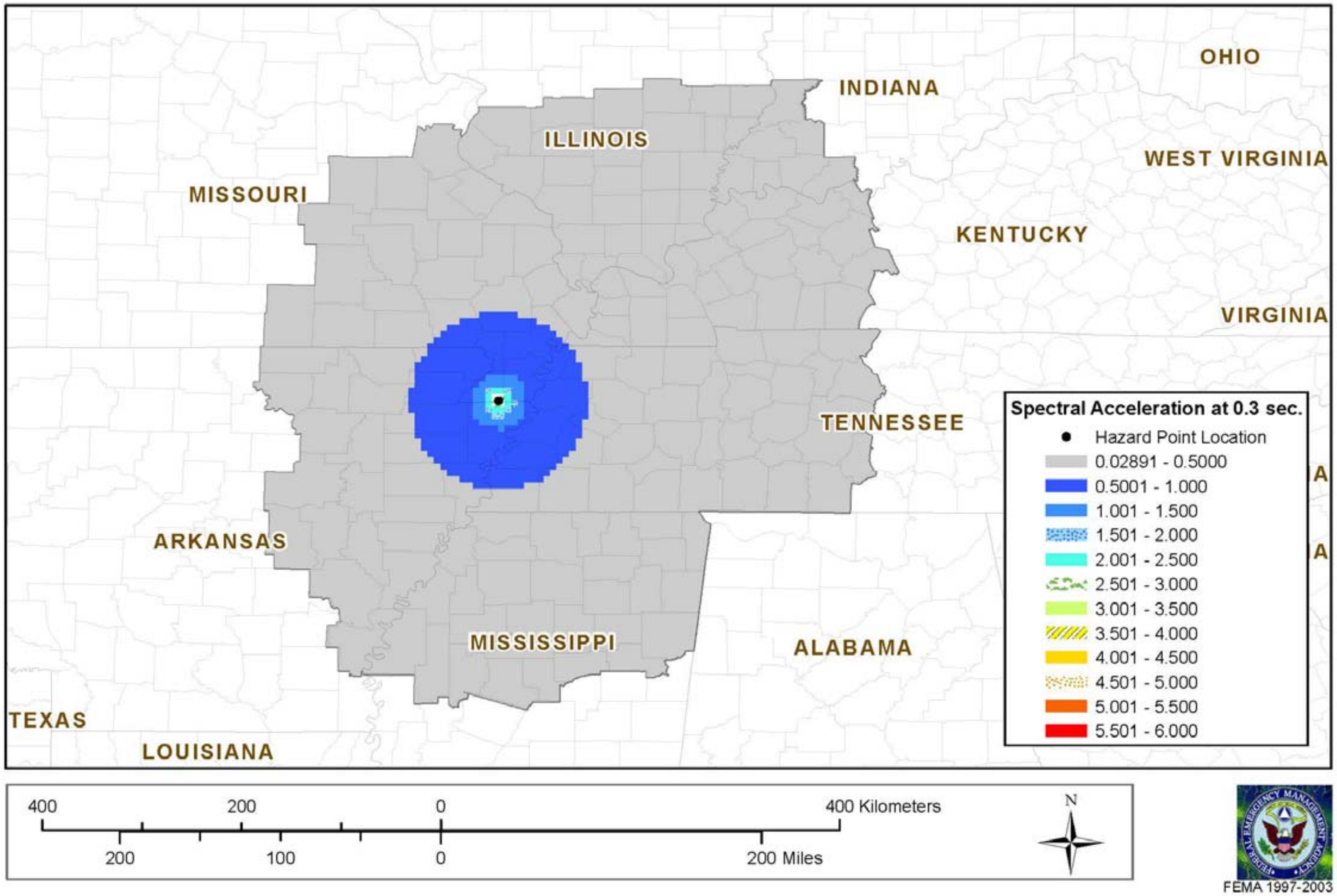
Peak Ground Acceleration
Study Region: CC C 4026 77 10 H
Hazard Scenario: 16 December 1811 Point Location, M7.7



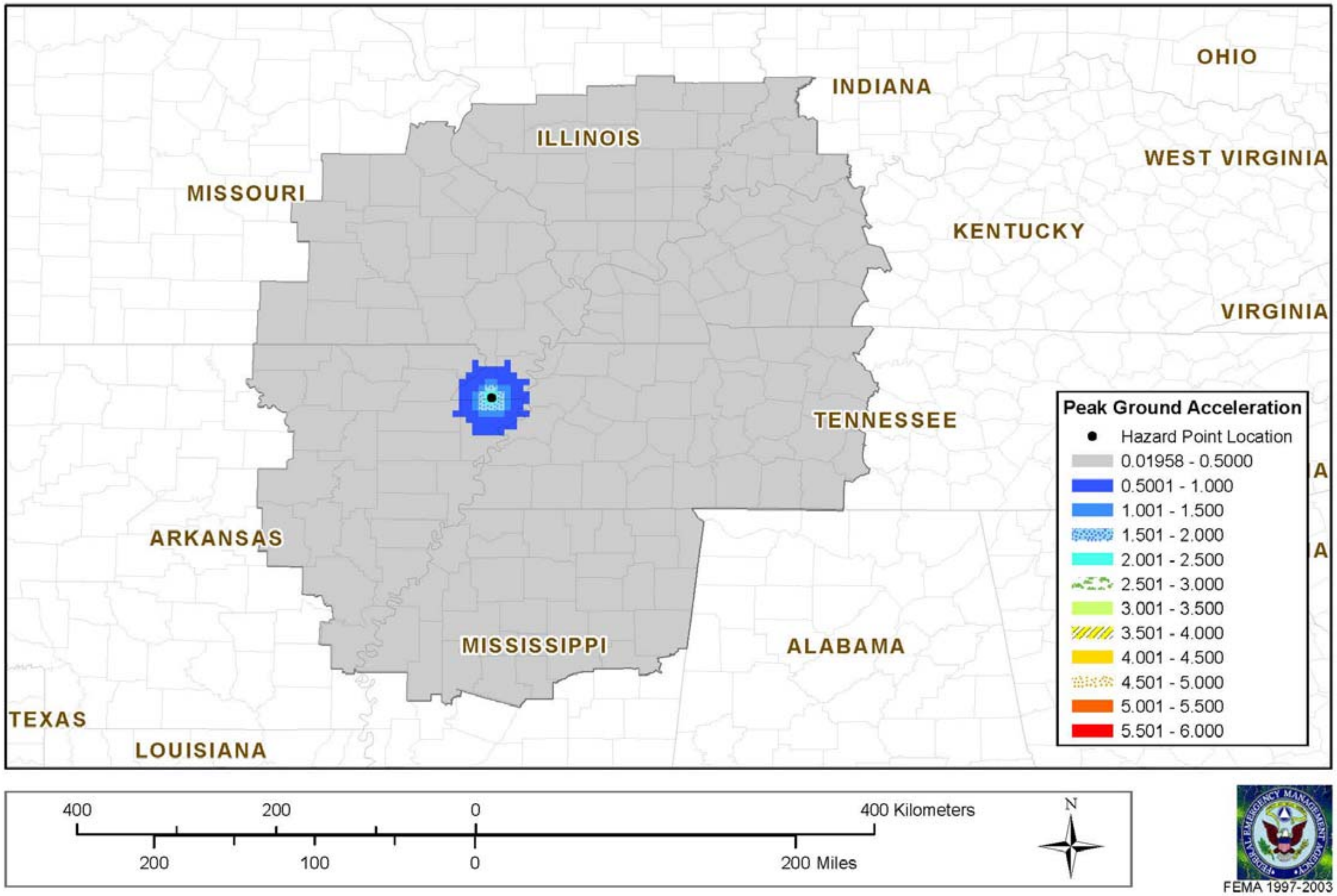
Spectral Acceleration at 1.0 sec.
Study Region: CC C 4026 77 10 H
Hazard Scenario: 16 December 1811 Point Location, M7.7



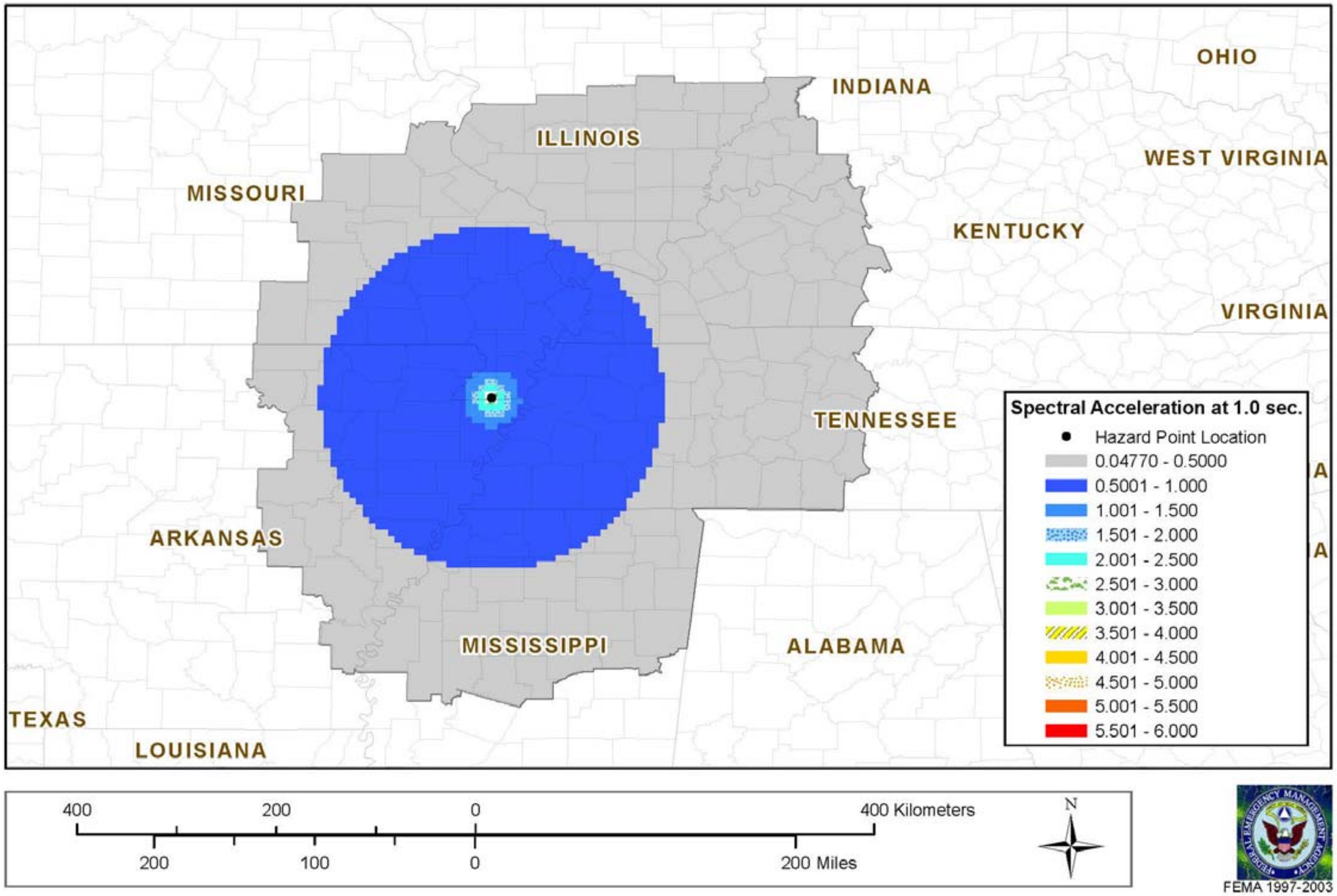
Spectral Acceleration at 0.3 sec.
Study Region: CC C 4026 77 10 H
Hazard Scenario: 16 December 1811 Point Location, M7.7



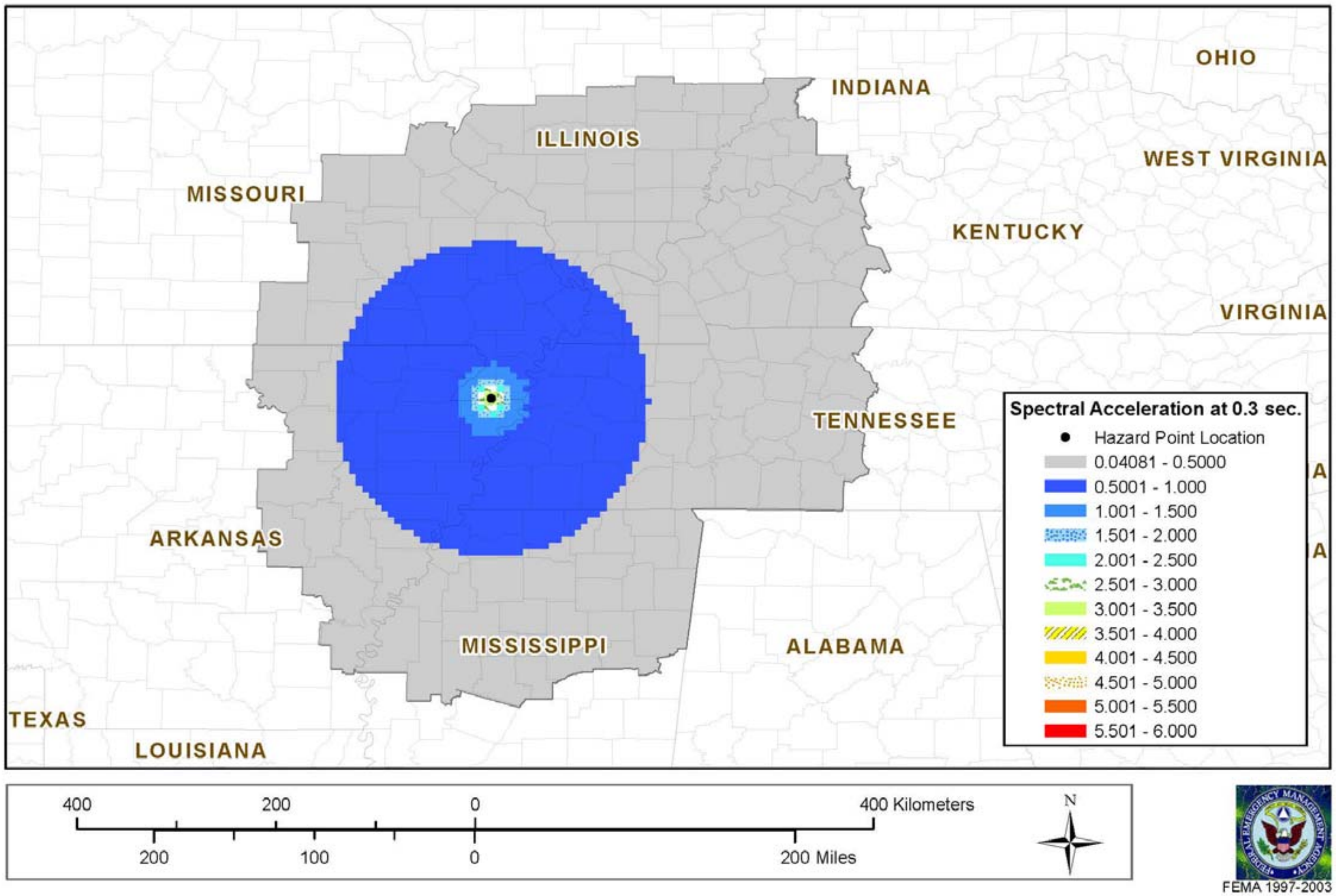
Peak Ground Acceleration
Study Region: CC C 4026 82 10 H
Hazard Scenario: 16 December 1811 Point Location, M8.2



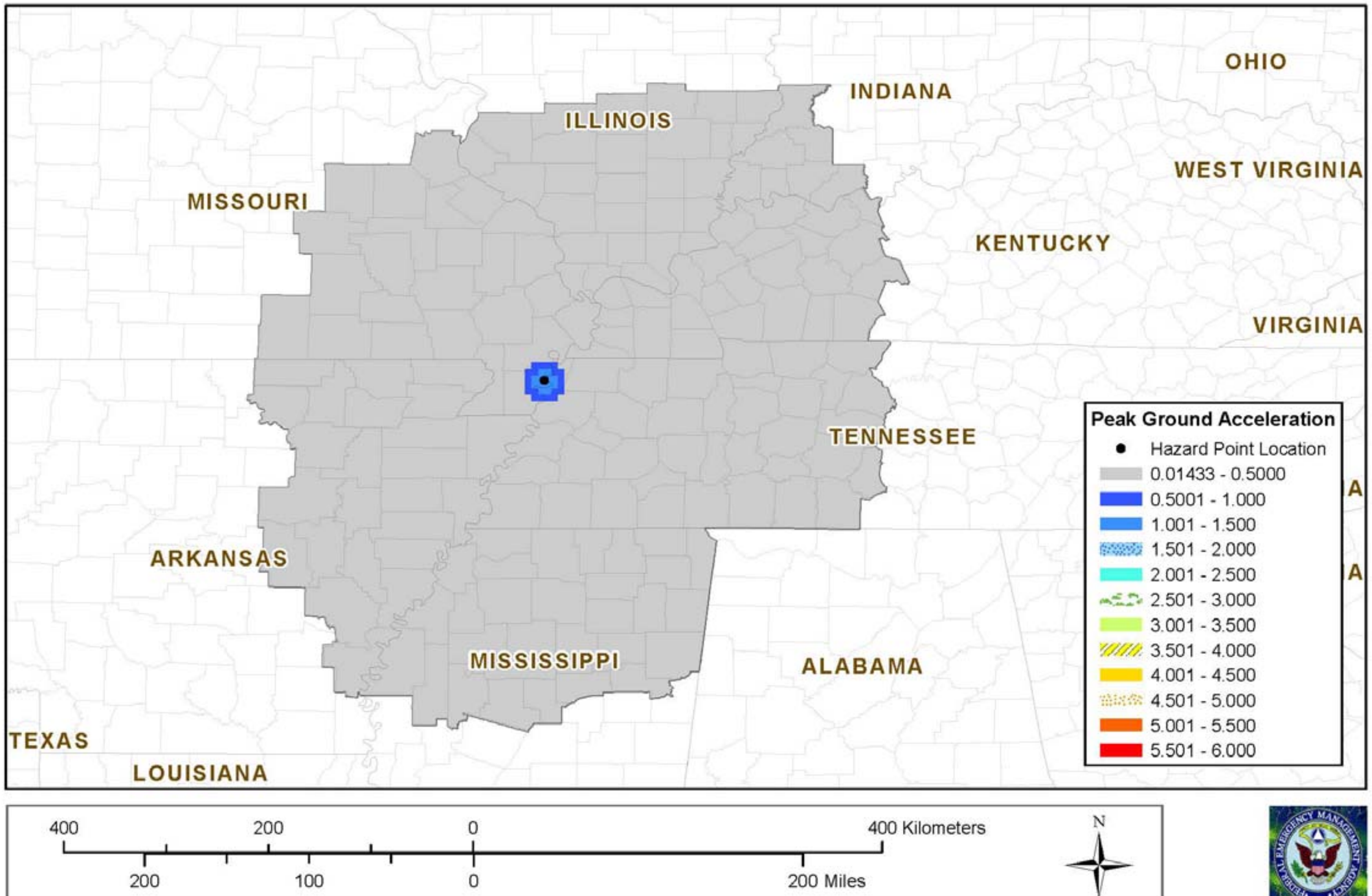
Spectral Acceleration at 1.0 sec.
Study Region: CC C 4026 82 10 H
Hazard Scenario: 16 December 1811 Point Location, M8.2



Spectral Acceleration at 0.3 sec.
Study Region: CC C 4026 82 10 H
Hazard Scenario: 16 December 1811 Point Location, M8.2

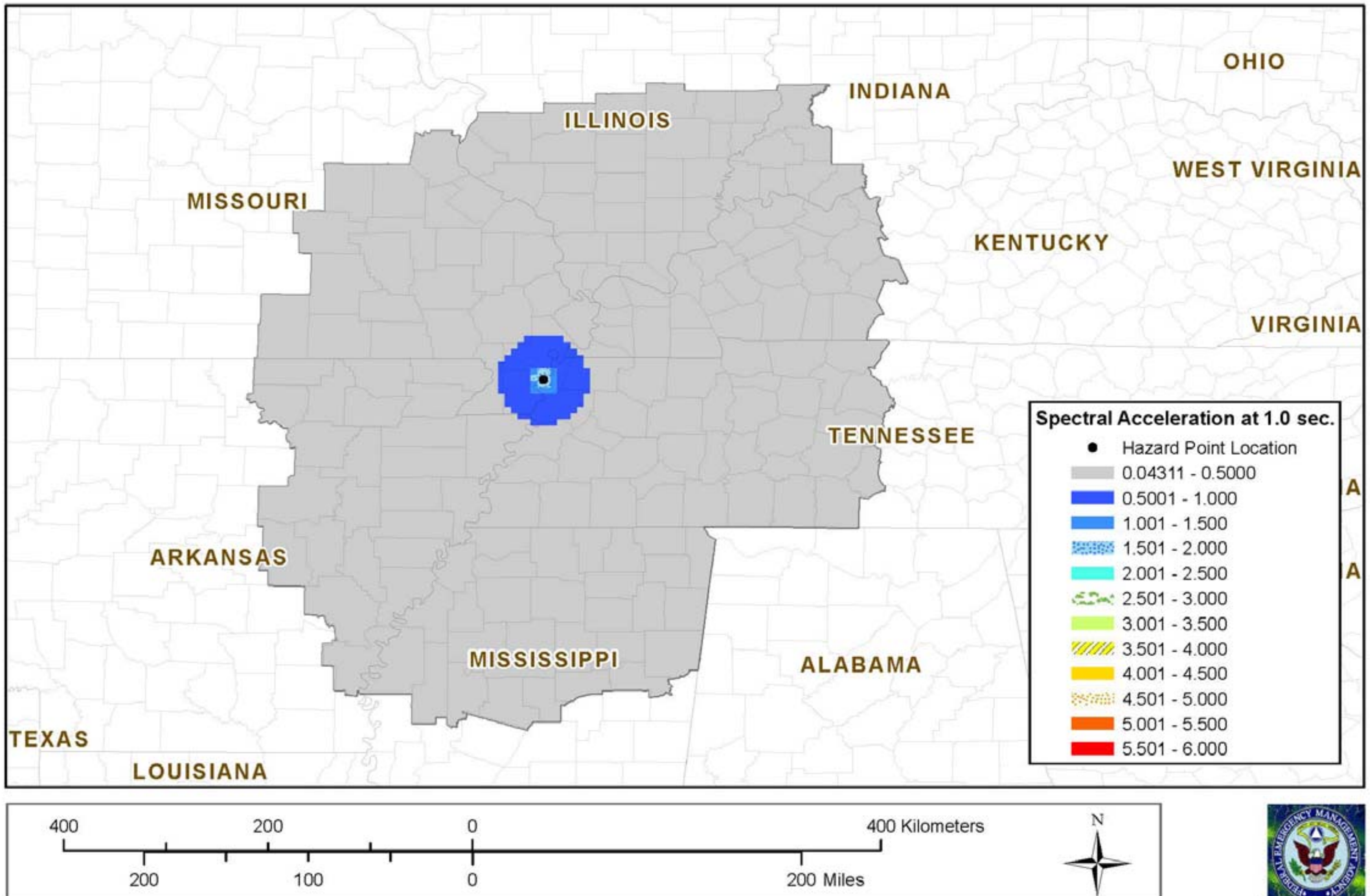


Peak Ground Acceleration
Study Region: CC C 4027 71 10 H
Hazard Scenario: 23 January 1812 Point Location, M7.1



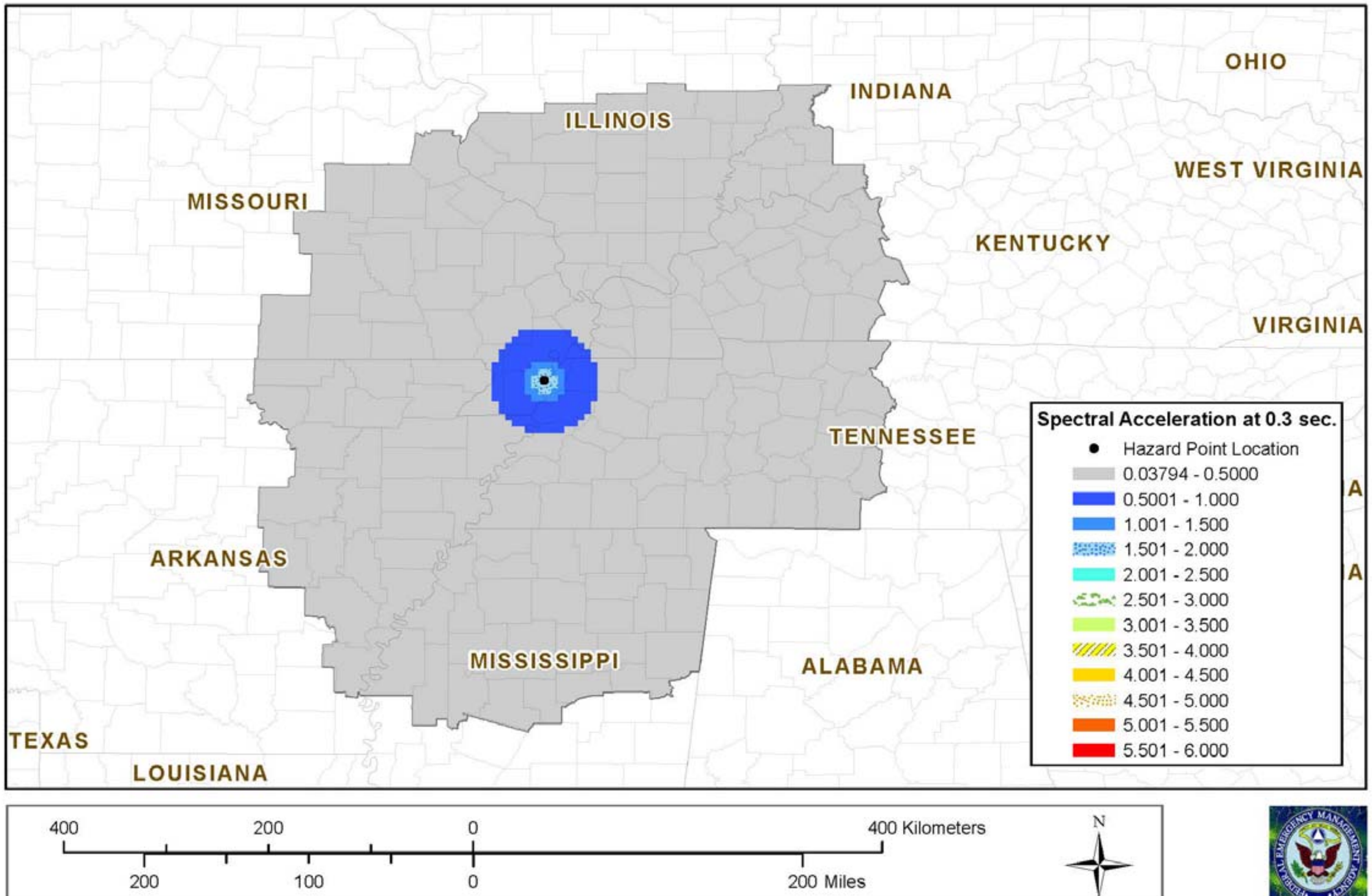
FEMA 1997-2003

Spectral Acceleration at 1.0 sec.
Study Region: CC C 4027 71 10 H
Hazard Scenario: 23 January 1812 Point Location, M7.1



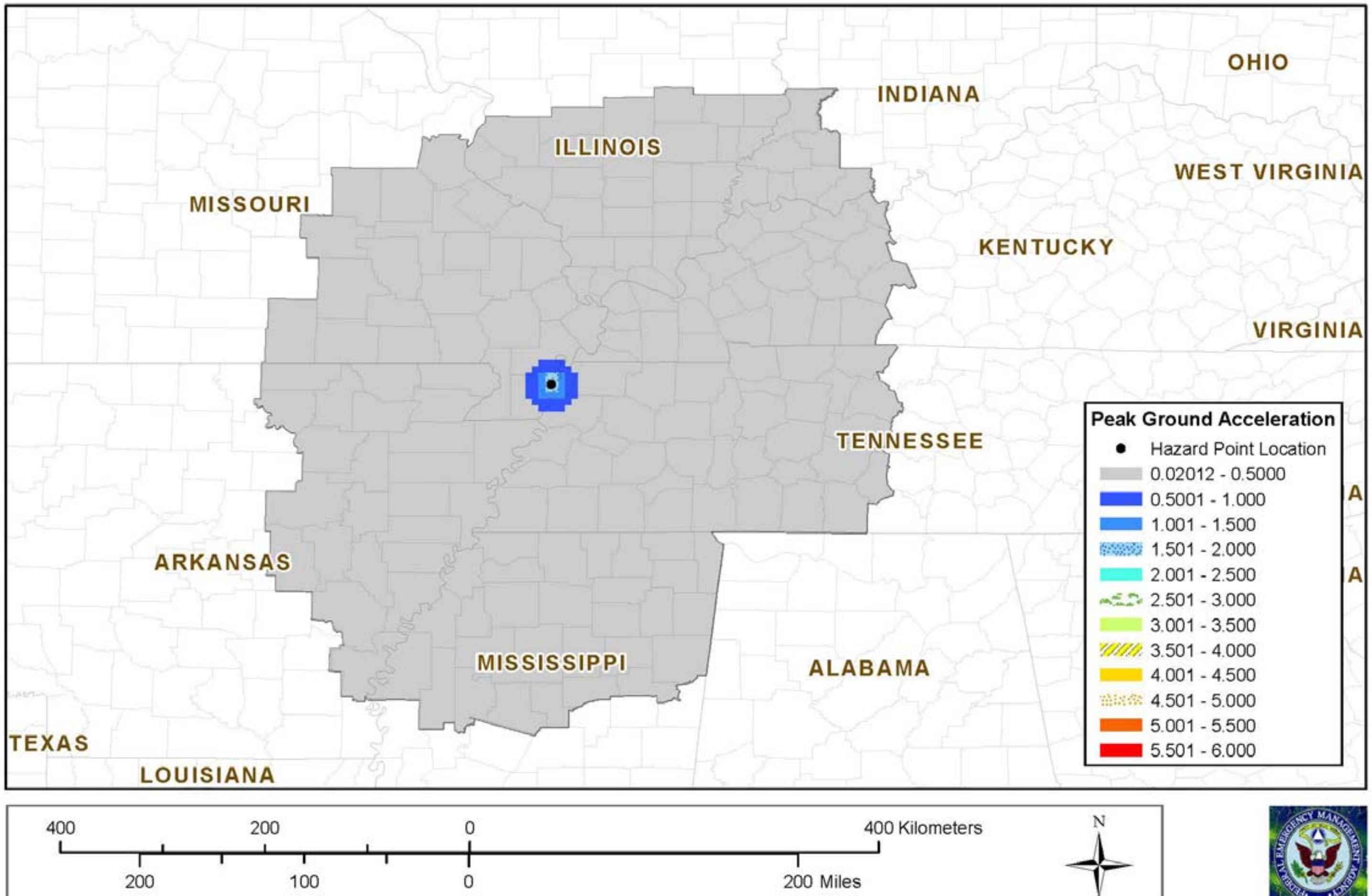
FEMA 1997-2003

Spectral Acceleration at 0.3 sec.
Study Region: CC C 4027 71 10 H
Hazard Scenario: 23 January 1812 Point Location, M7.1



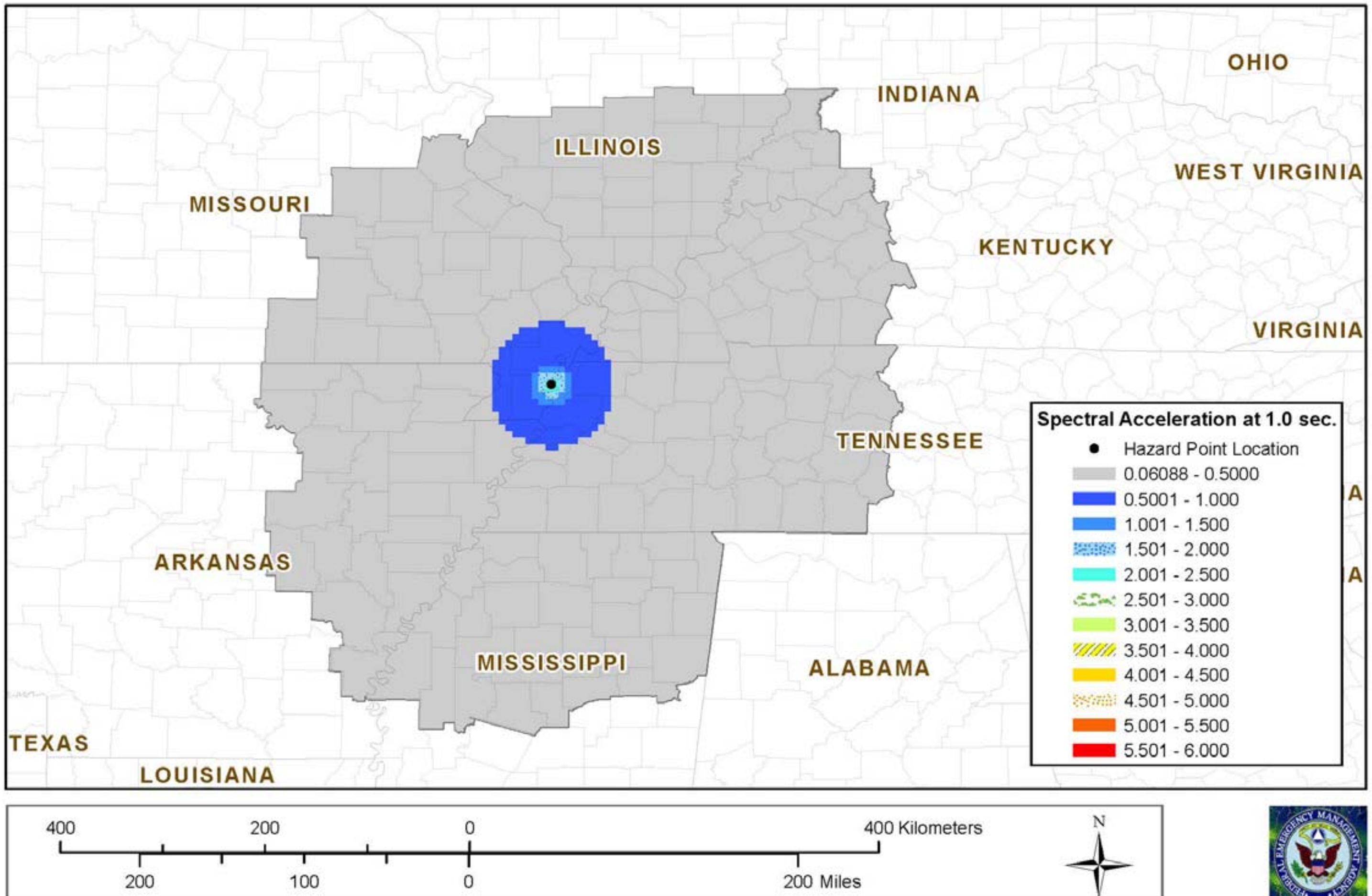
FEMA 1997-2003

Peak Ground Acceleration
Study Region: CC C 4027 75 10 H
Hazard Scenario: 23 January 1812 Point Location, M7.5



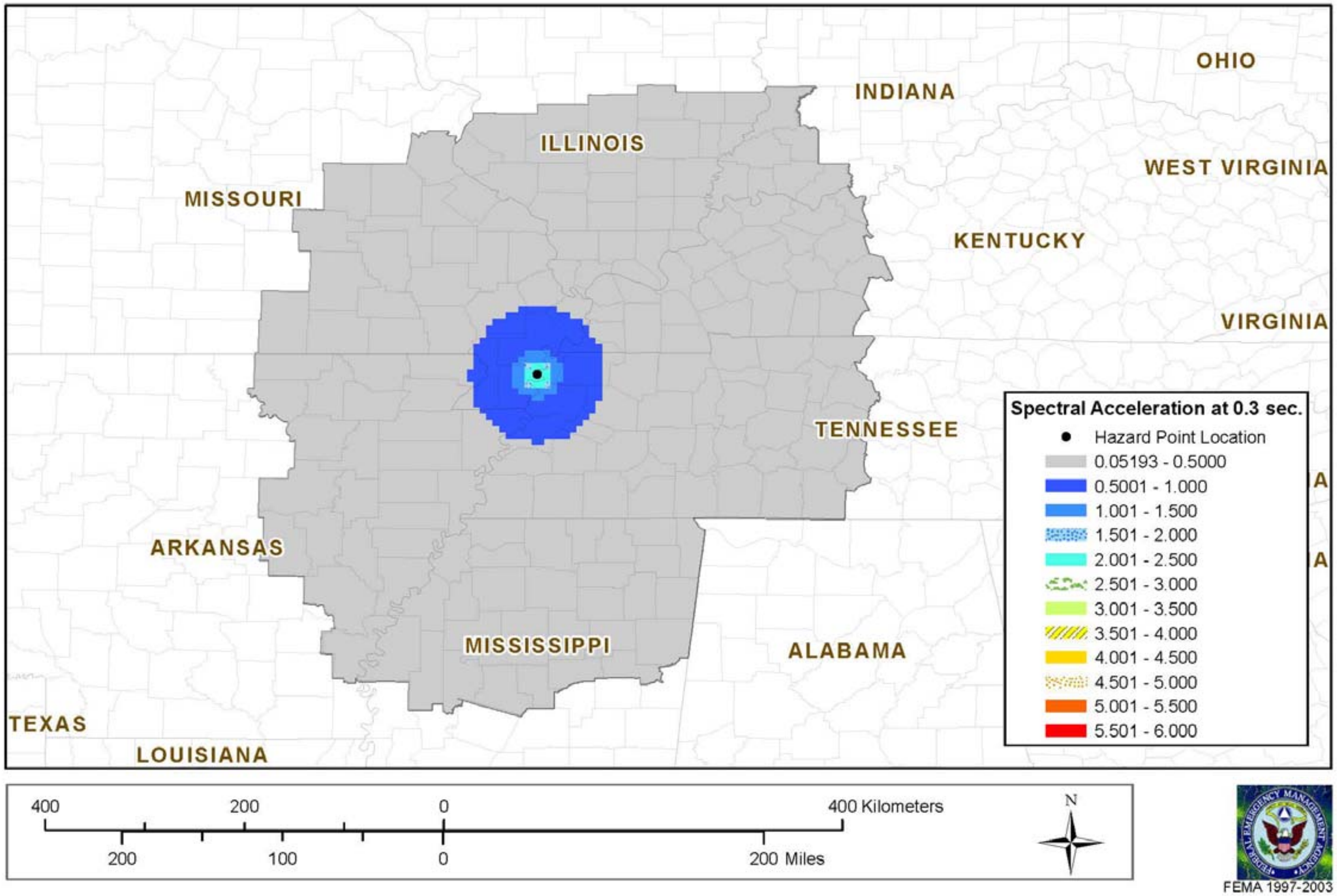
FEMA 1997-2003

Spectral Acceleration at 1.0 sec.
Study Region: CC C 4027 75 10 H
Hazard Scenario: 23 January 1812 Point Location, M7.5

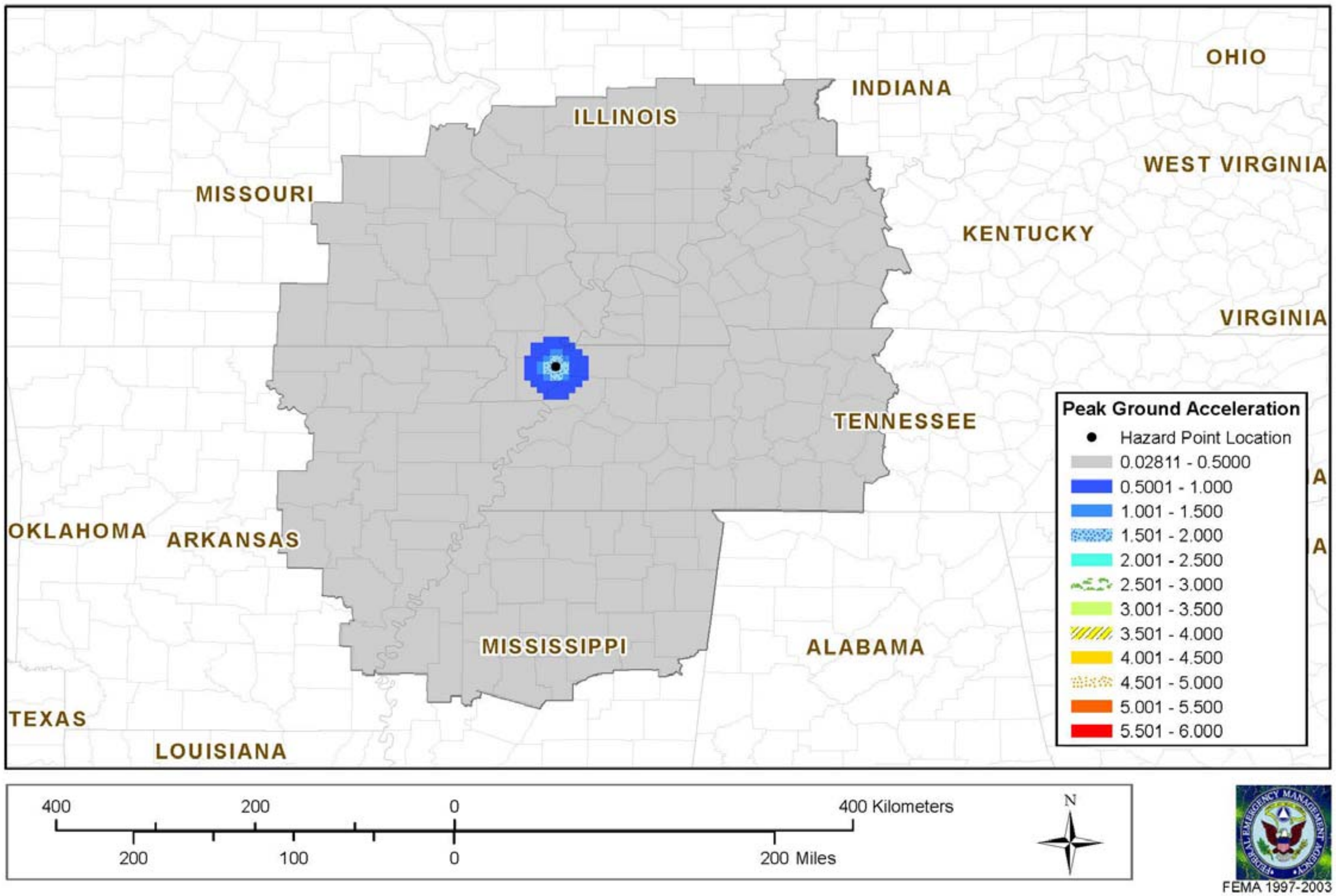


FEMA 1997-2003

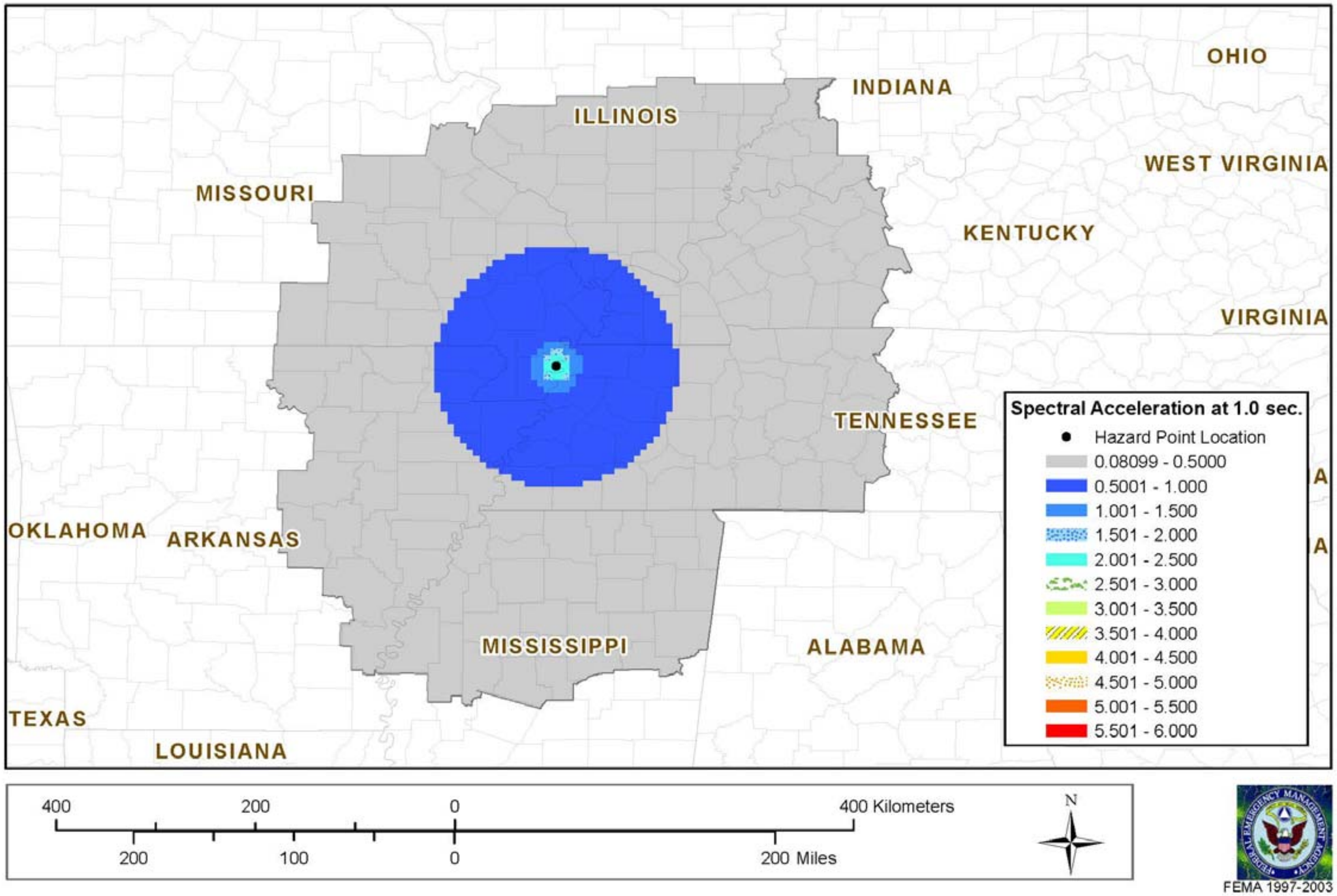
Spectral Acceleration at 0.3 sec.
Study Region: CC C 4027 75 10 H
Hazard Scenario: 23 January 1812 Point Location, M7.5



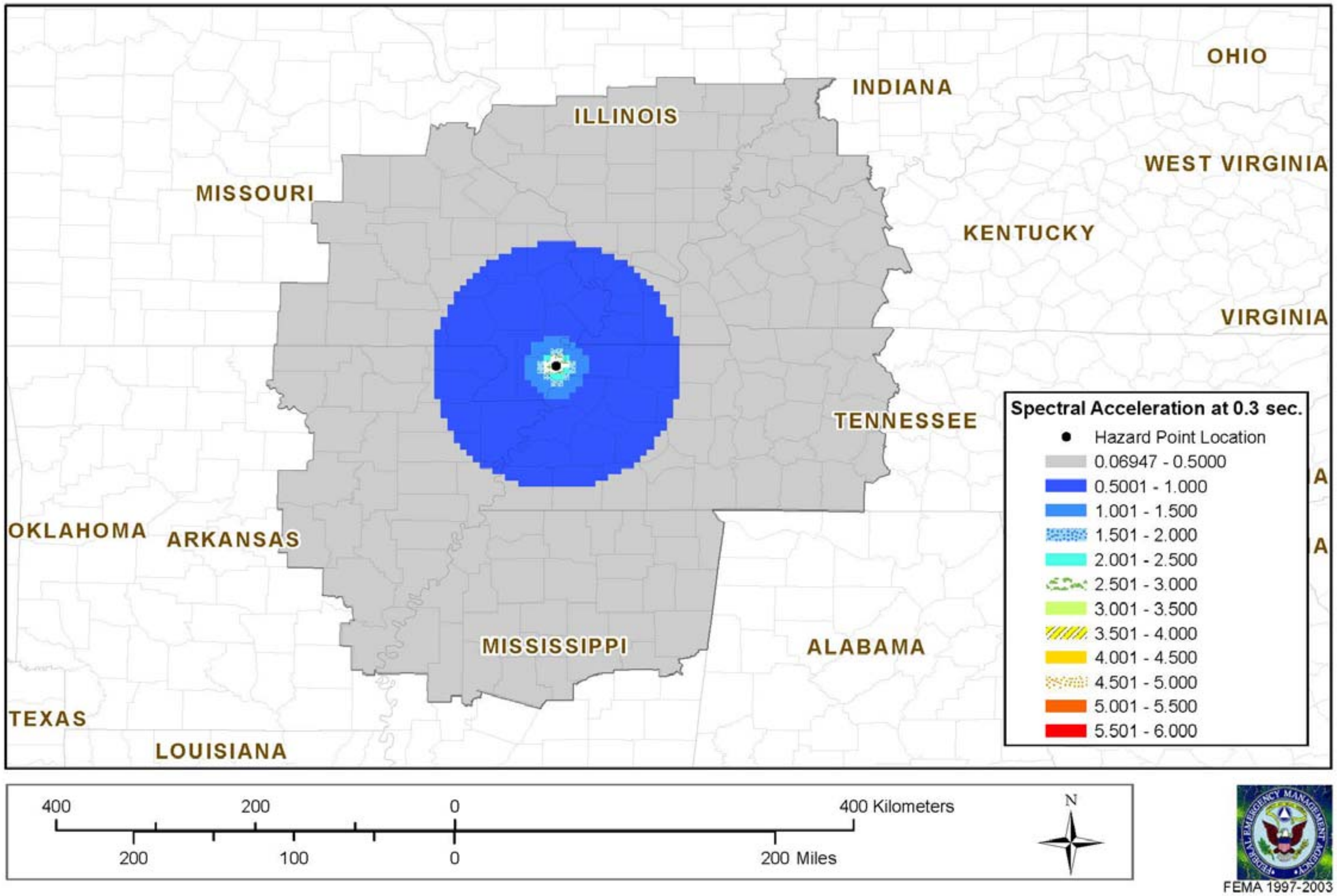
Peak Ground Acceleration
Study Region: CC C 4027 79 10 H
Hazard Scenario: 23 January 1812 Point Location, M7.9



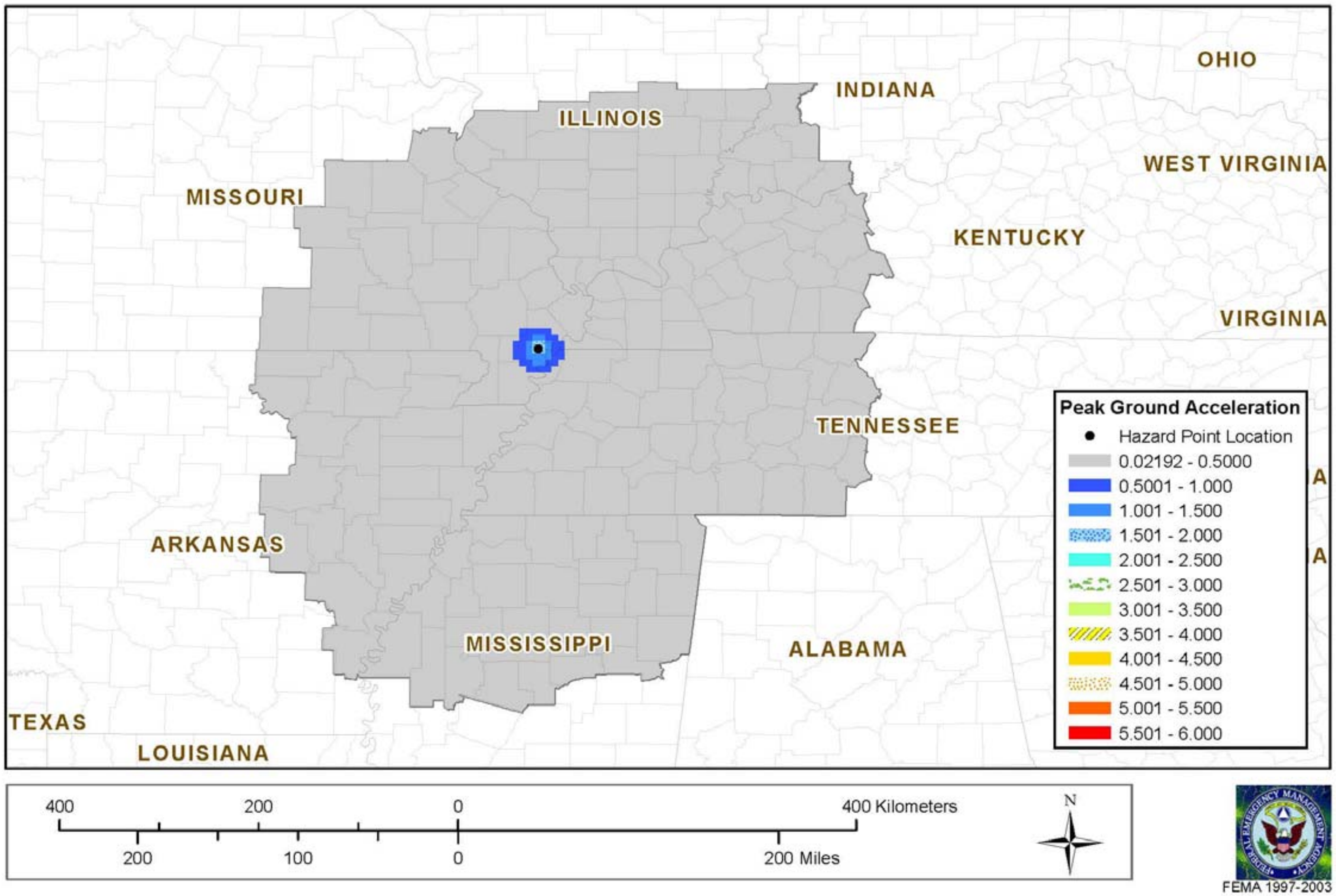
Spectral Acceleration at 1.0 sec.
Study Region: CC C 4027 79 10 H
Hazard Scenario: 23 January 1812 Point Location, M7.9



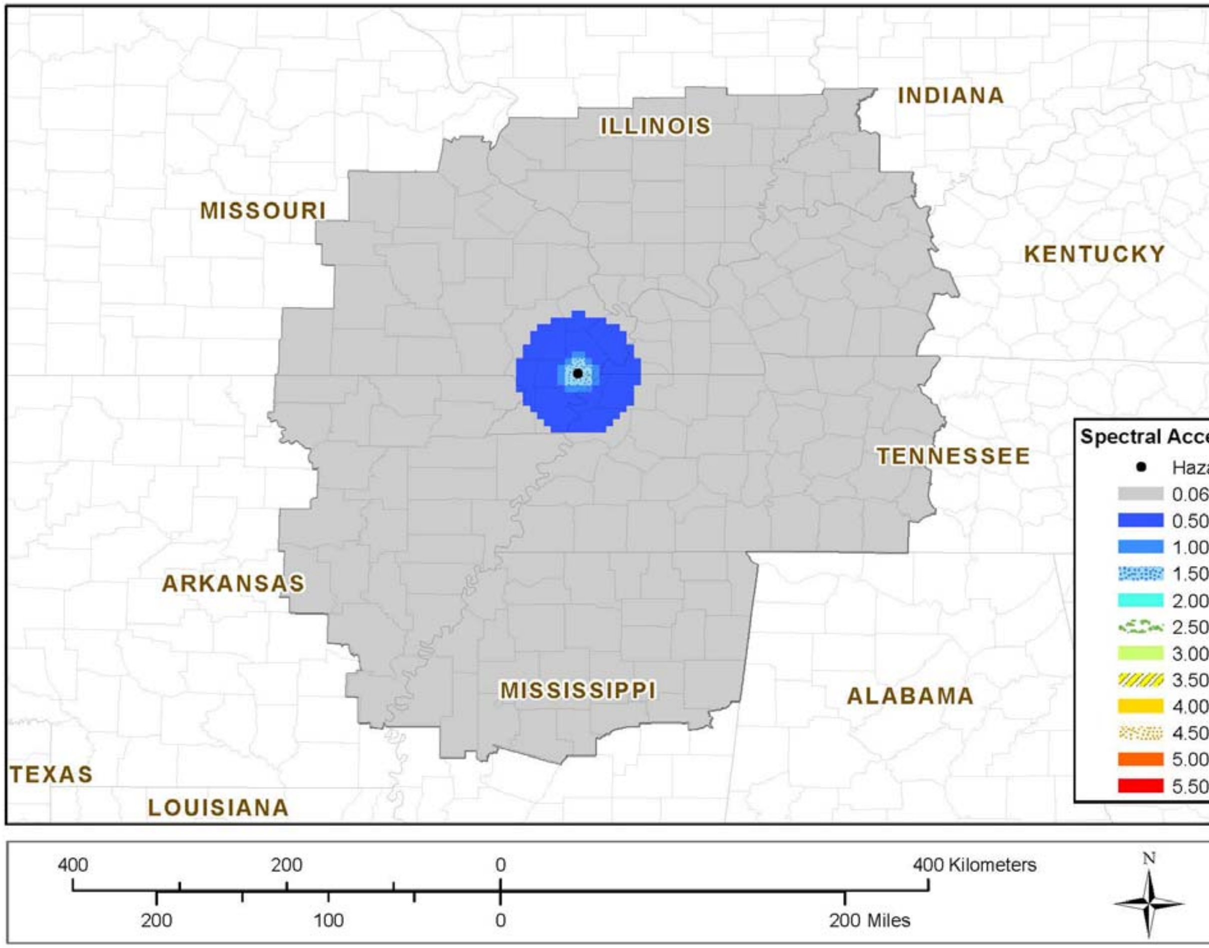
Spectral Acceleration at 0.3 sec.
Study Region: CC C 4027 79 10 H
Hazard Scenario: 23 January 1812 Point Location, M7.9



Peak Ground Acceleration
Study Region: CC C 4028 74 10 H
Hazard Scenario: 7 February 1812 Point Location, M7.4

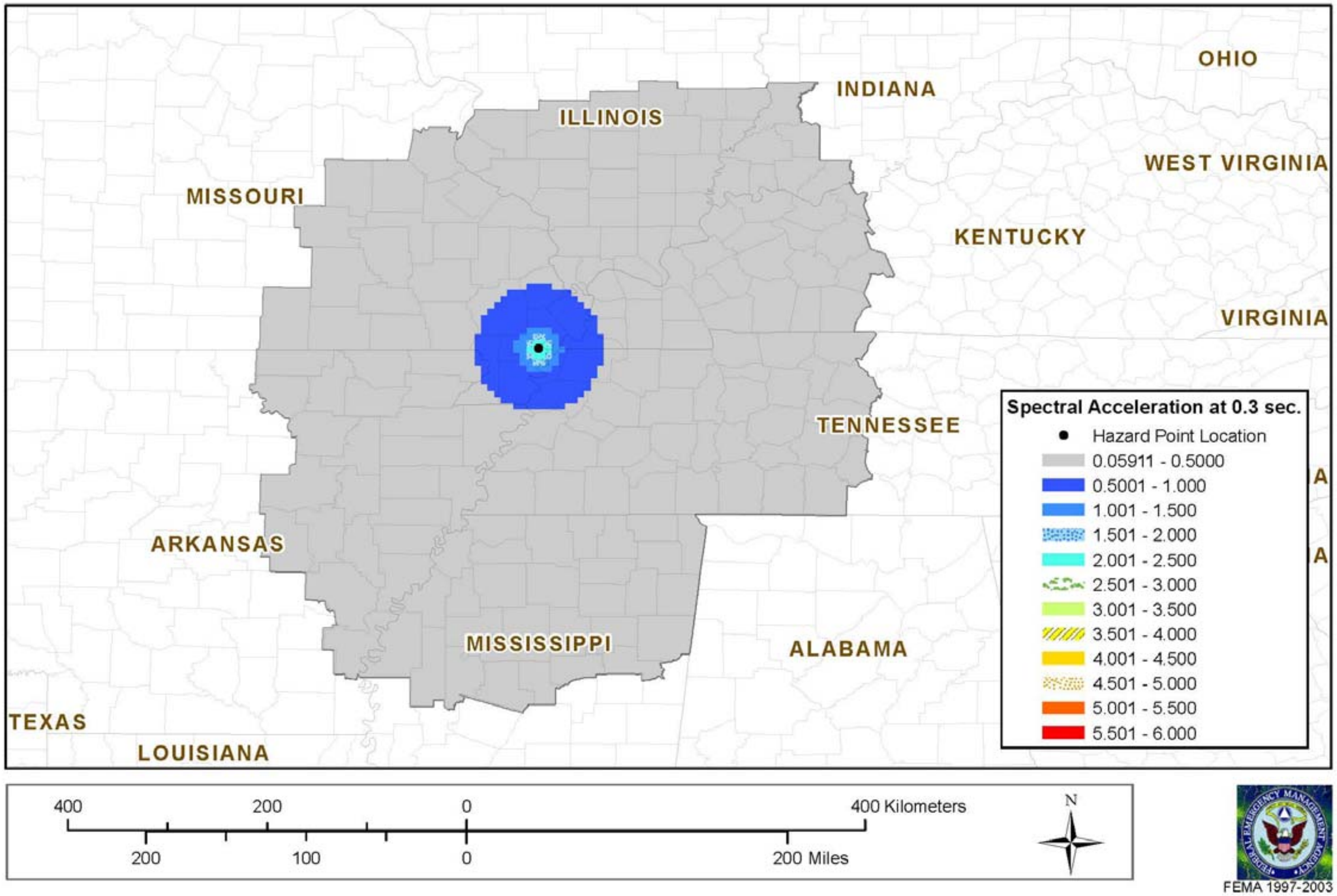


Spectral Acceleration at 1.0 sec.
Study Region: CC C 4028 74 10 H
Hazard Scenario: 7 February 1812 Point Location, M7.4

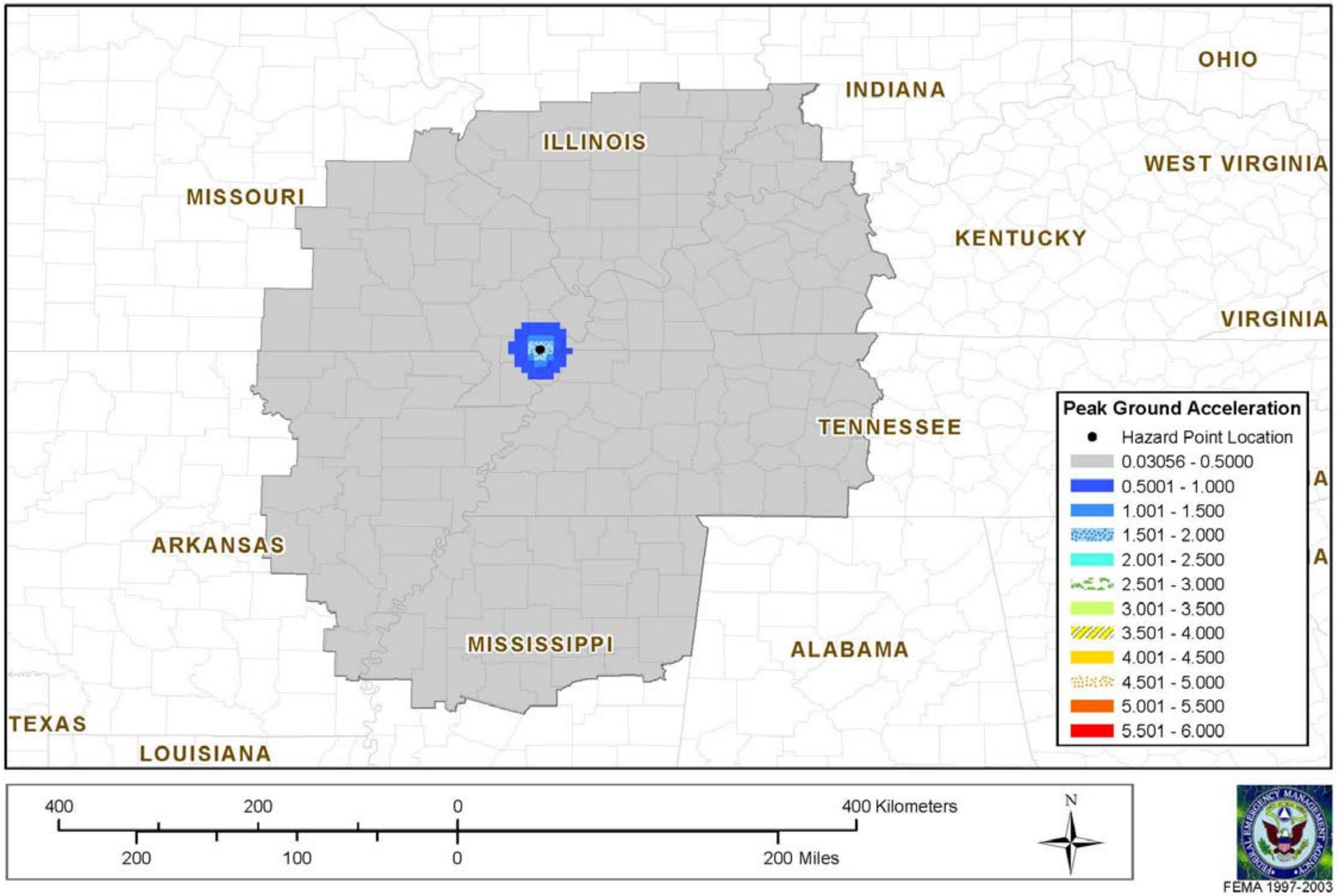


FEMA 1997-2003

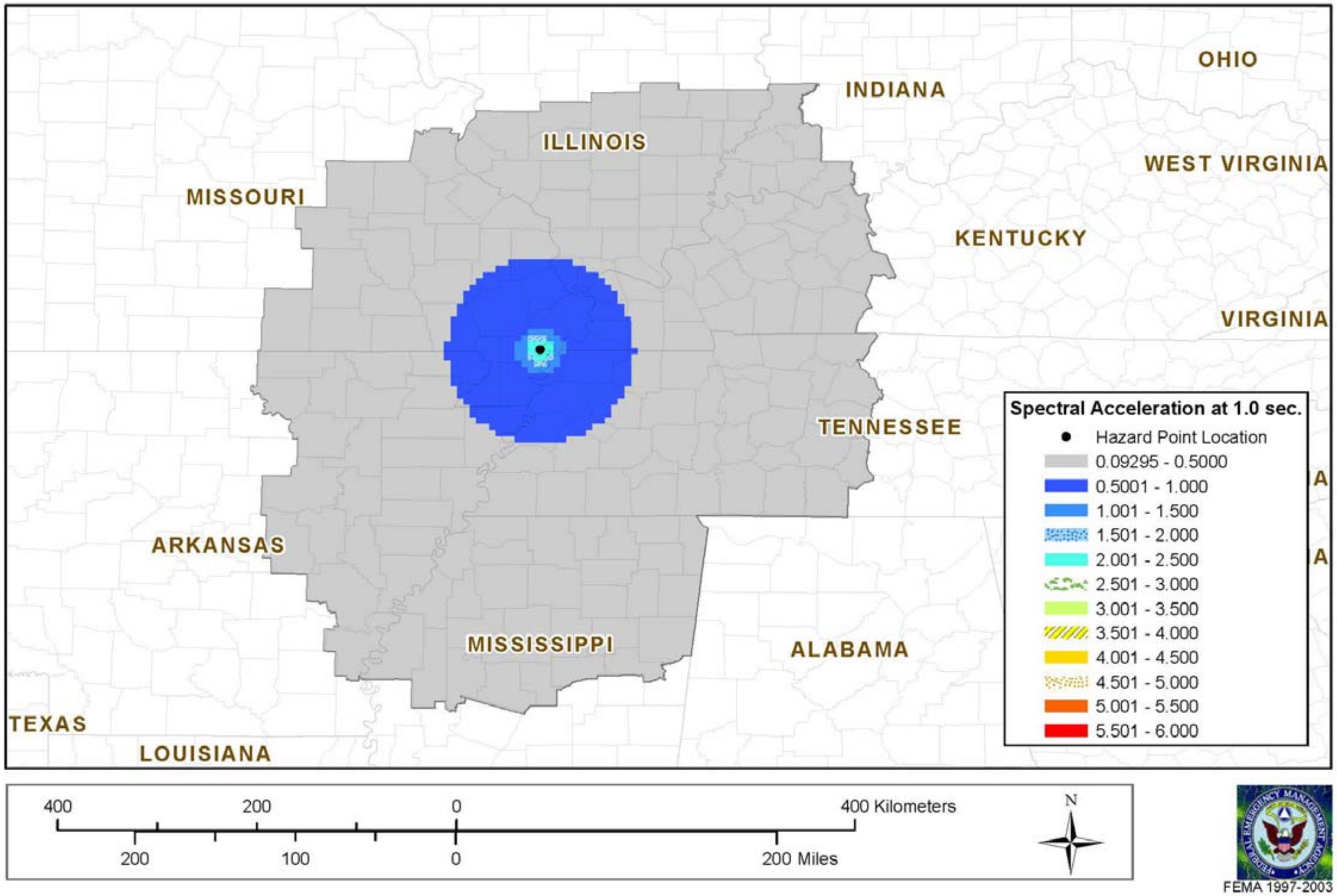
Spectral Acceleration at 0.3 sec.
Study Region: CC C 4028 74 10 H
Hazard Scenario: 7 February 1812 Point Location, M7.4



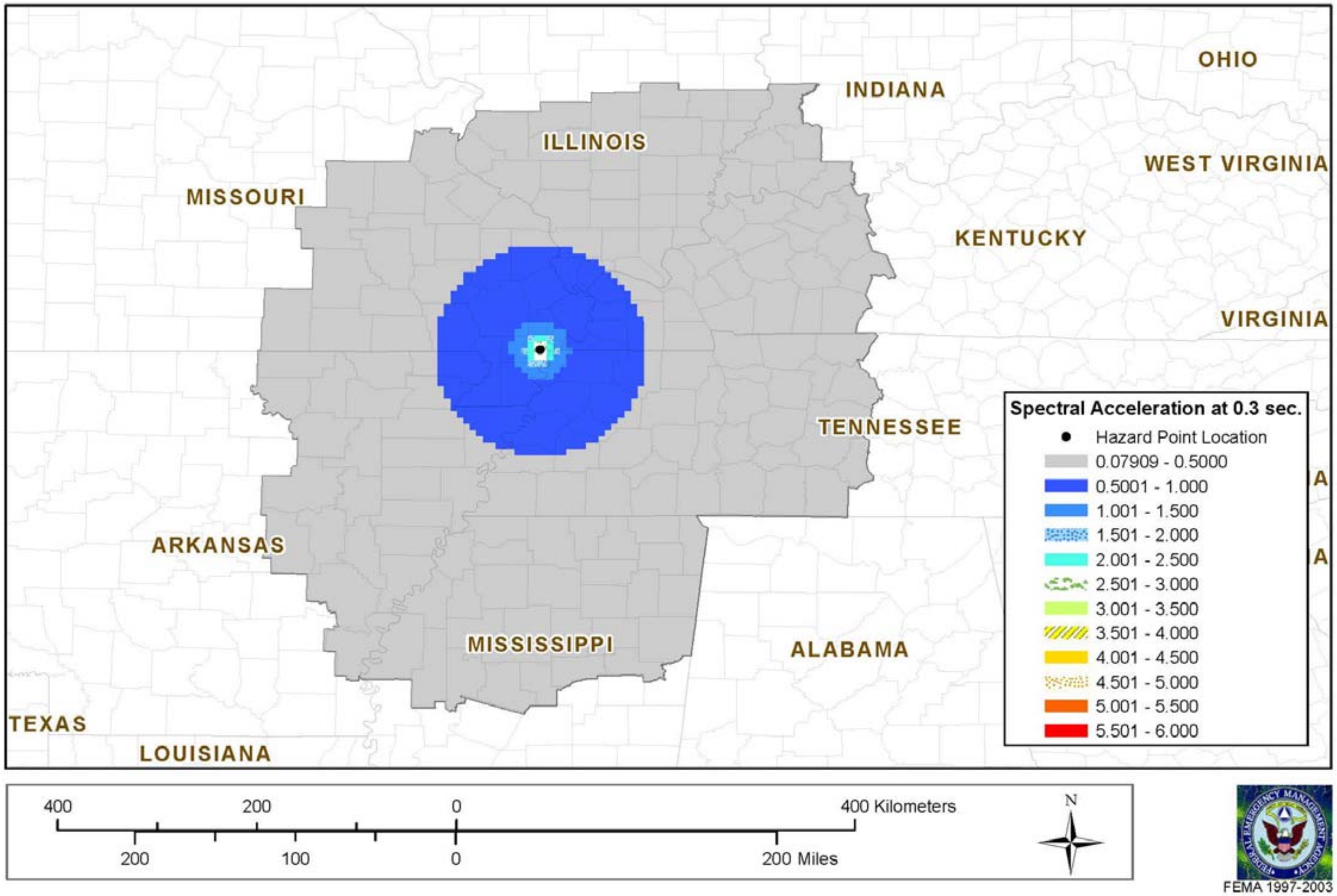
Peak Ground Acceleration
Study Region: CC C 4028 78 10 H
Hazard Scenario: 7 February 1812 Point Location, M7.8



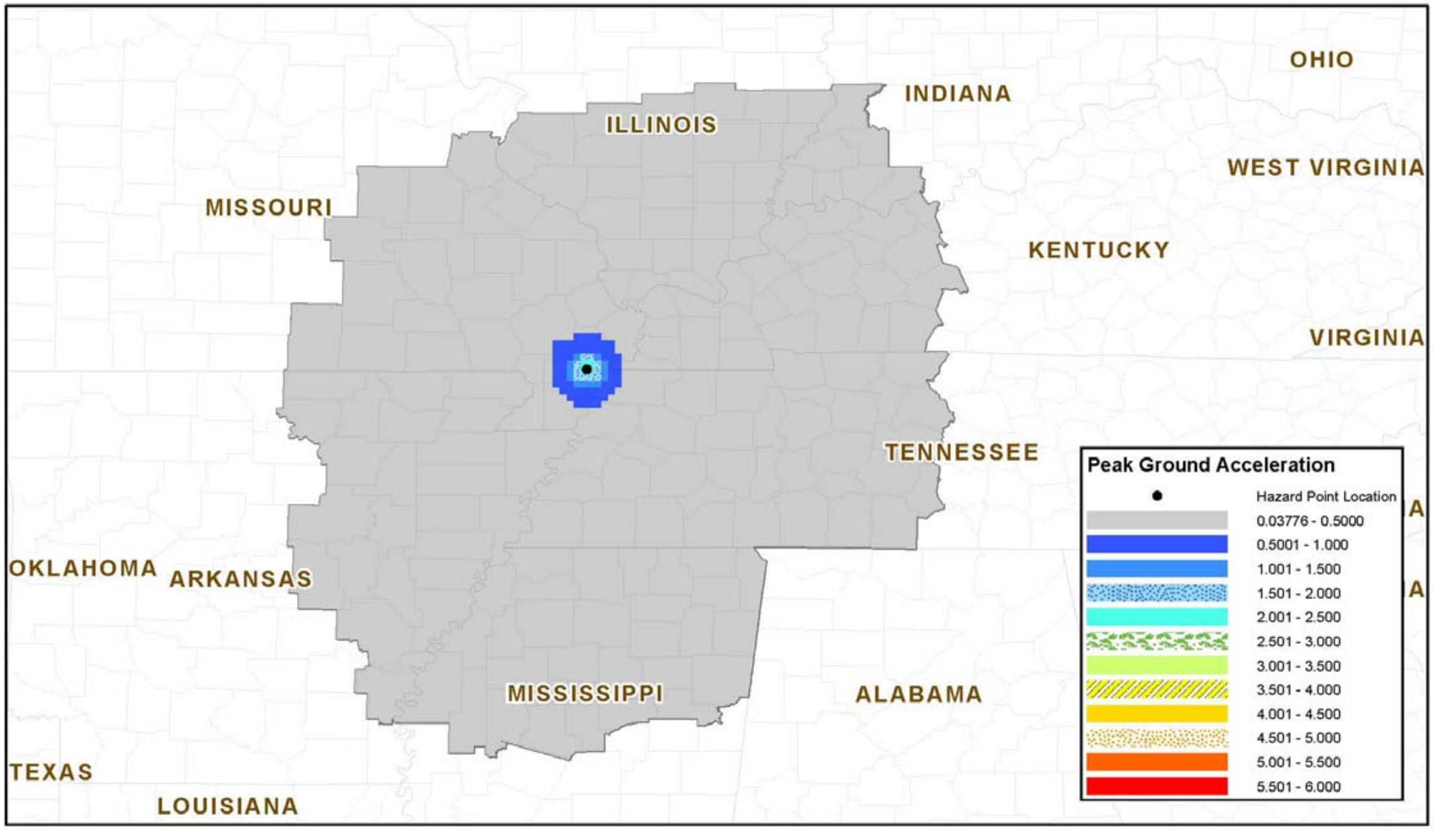
Spectral Acceleration at 1.0 sec.
Study Region: CC C 4028 78 10 H
Hazard Scenario: 7 February 1812 Point Location, M7.8

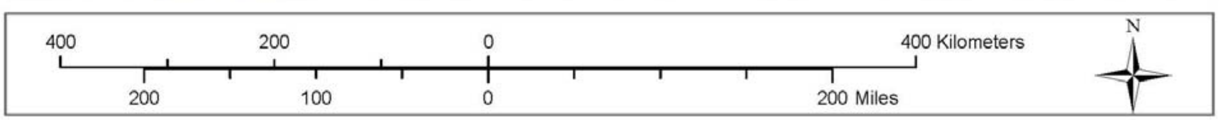


Spectral Acceleration at 0.3 sec.
Study Region: CC C 4028 78 10 H
Hazard Scenario: 7 February 1812 Point Location, M7.8



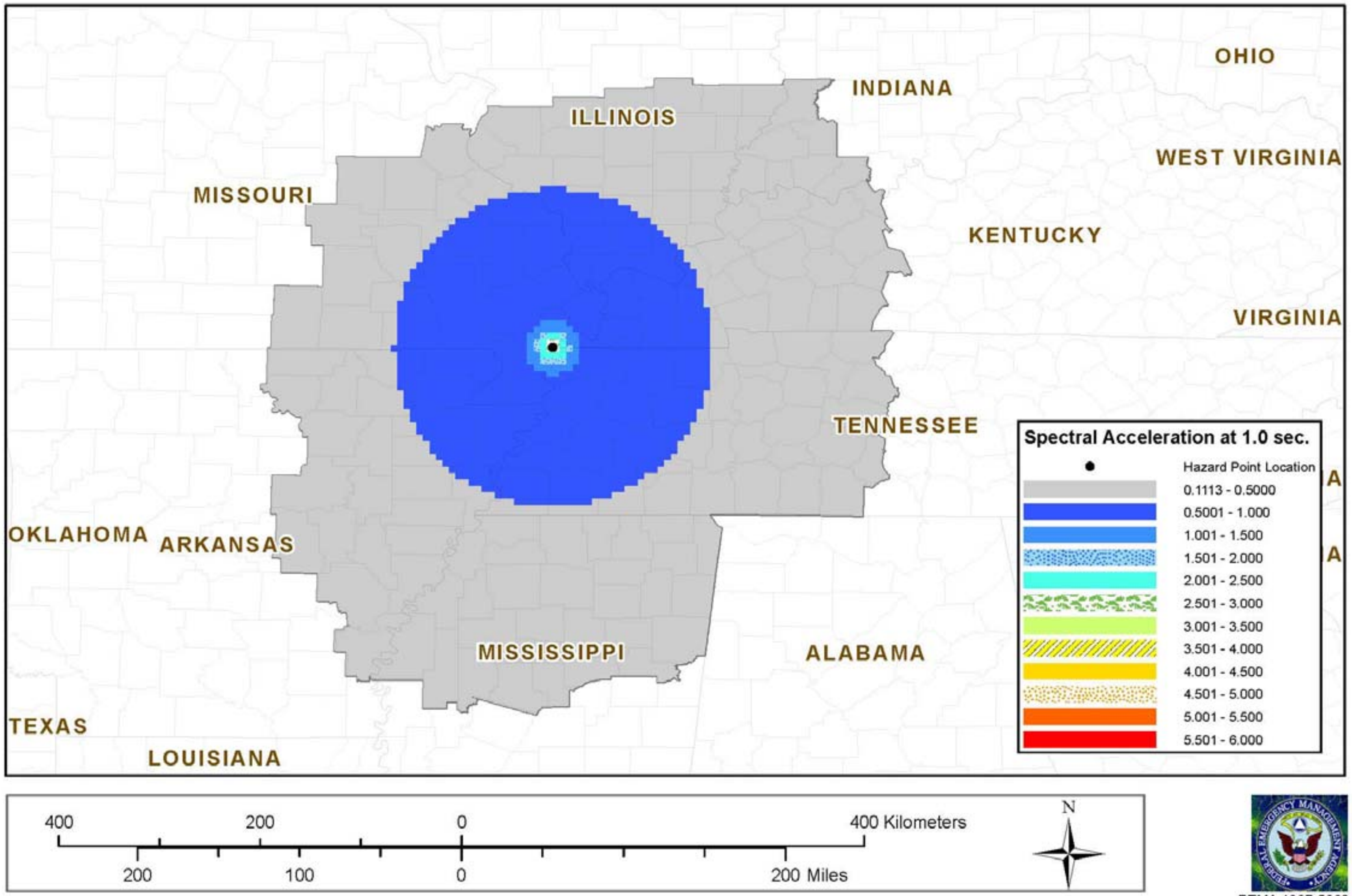
Peak Ground Acceleration
Study Region: CC C 4028 81 10 H
Hazard Scenario: 7 February 1812 Point Location, M8.1





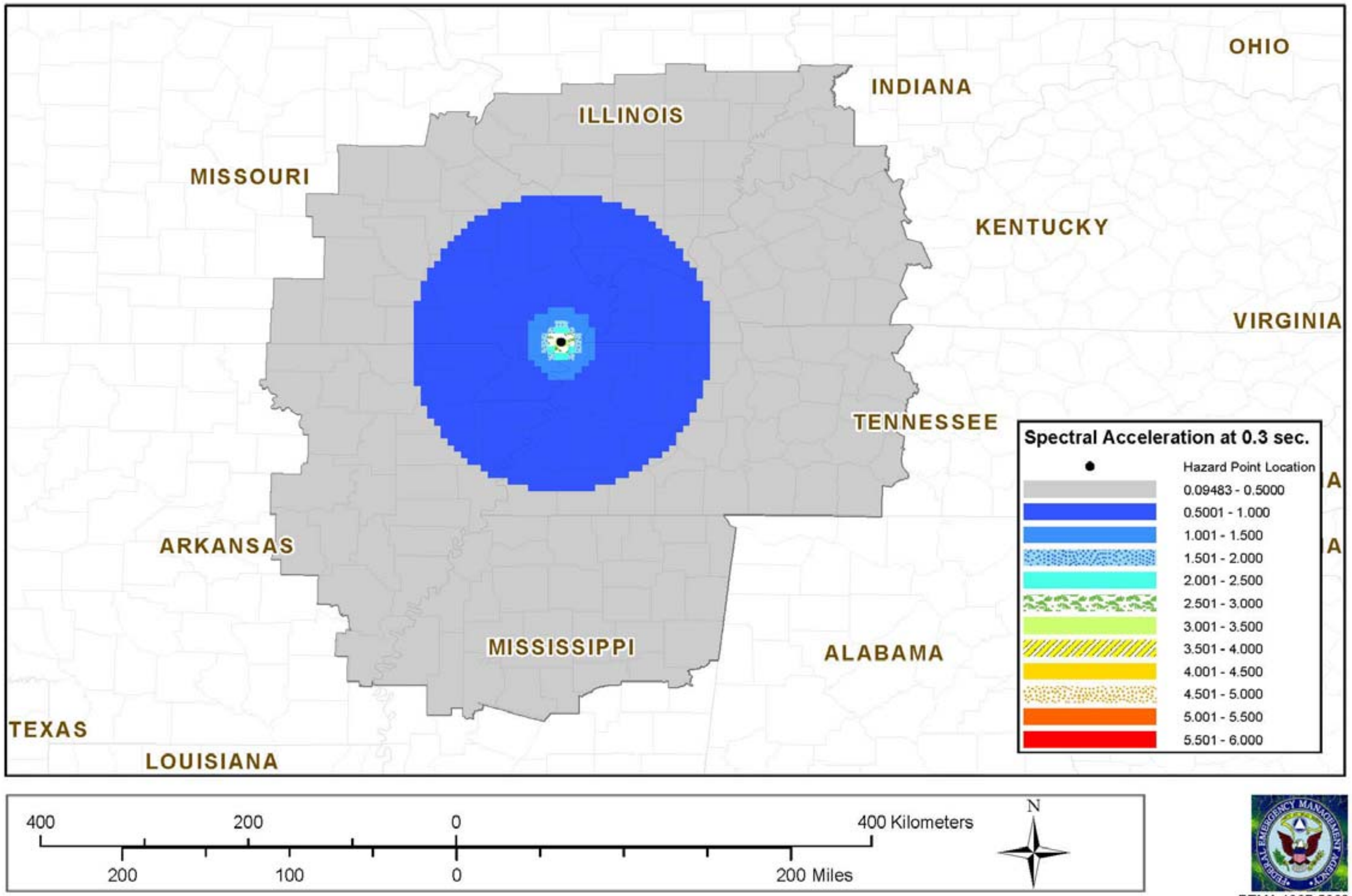
FEMA 1997-2003

Spectral Acceleration at 1.0 sec.
Study Region: CC C 4028 81 10 H
Hazard Scenario: 7 February 1812 Point Location, M8.1



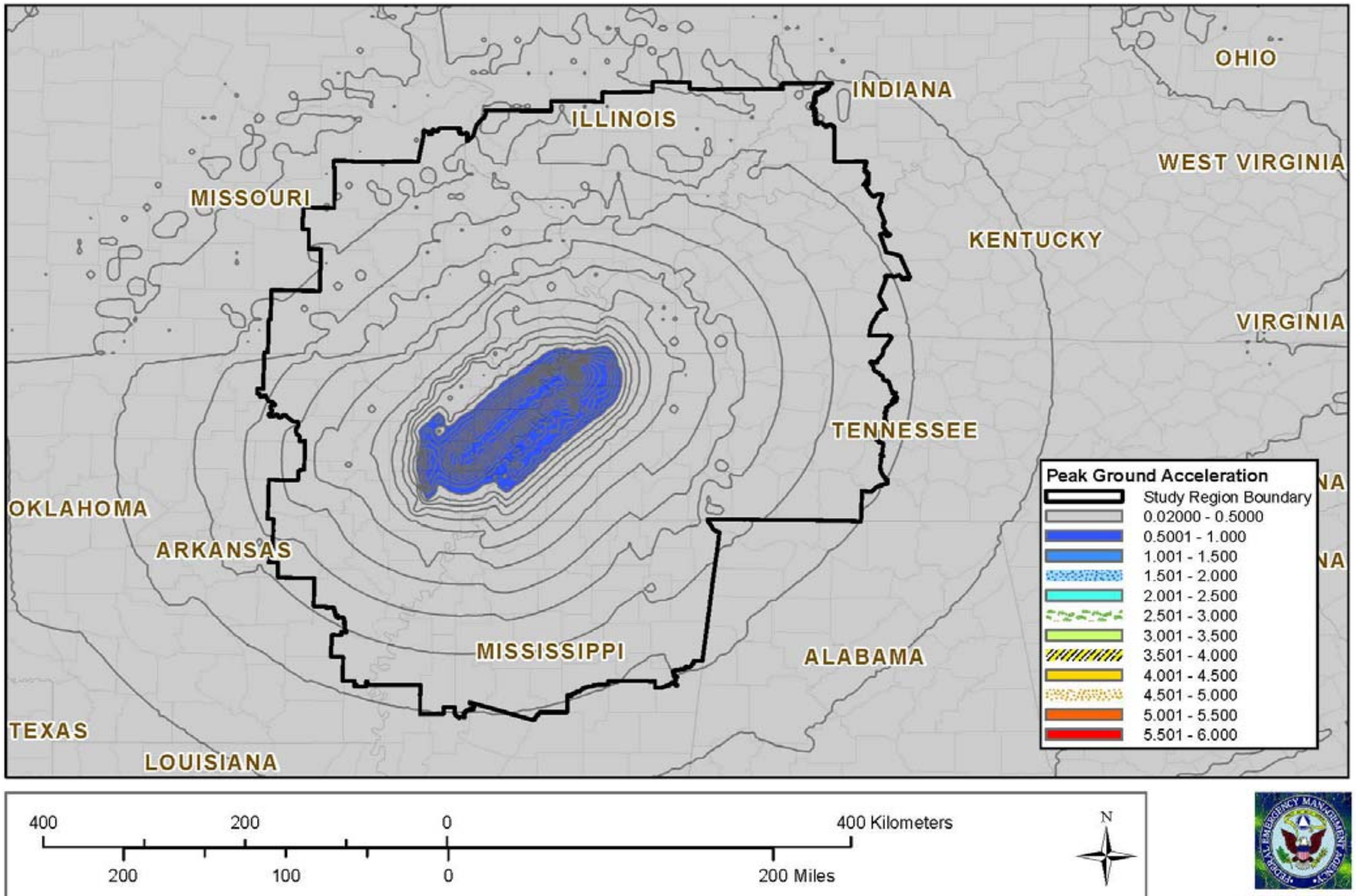
FEMA 1997-2003

Spectral Acceleration at 0.3 sec.
Study Region: CC C 4028 81 10 H
Hazard Scenario: 7 February 1812 Point Location, M8.1

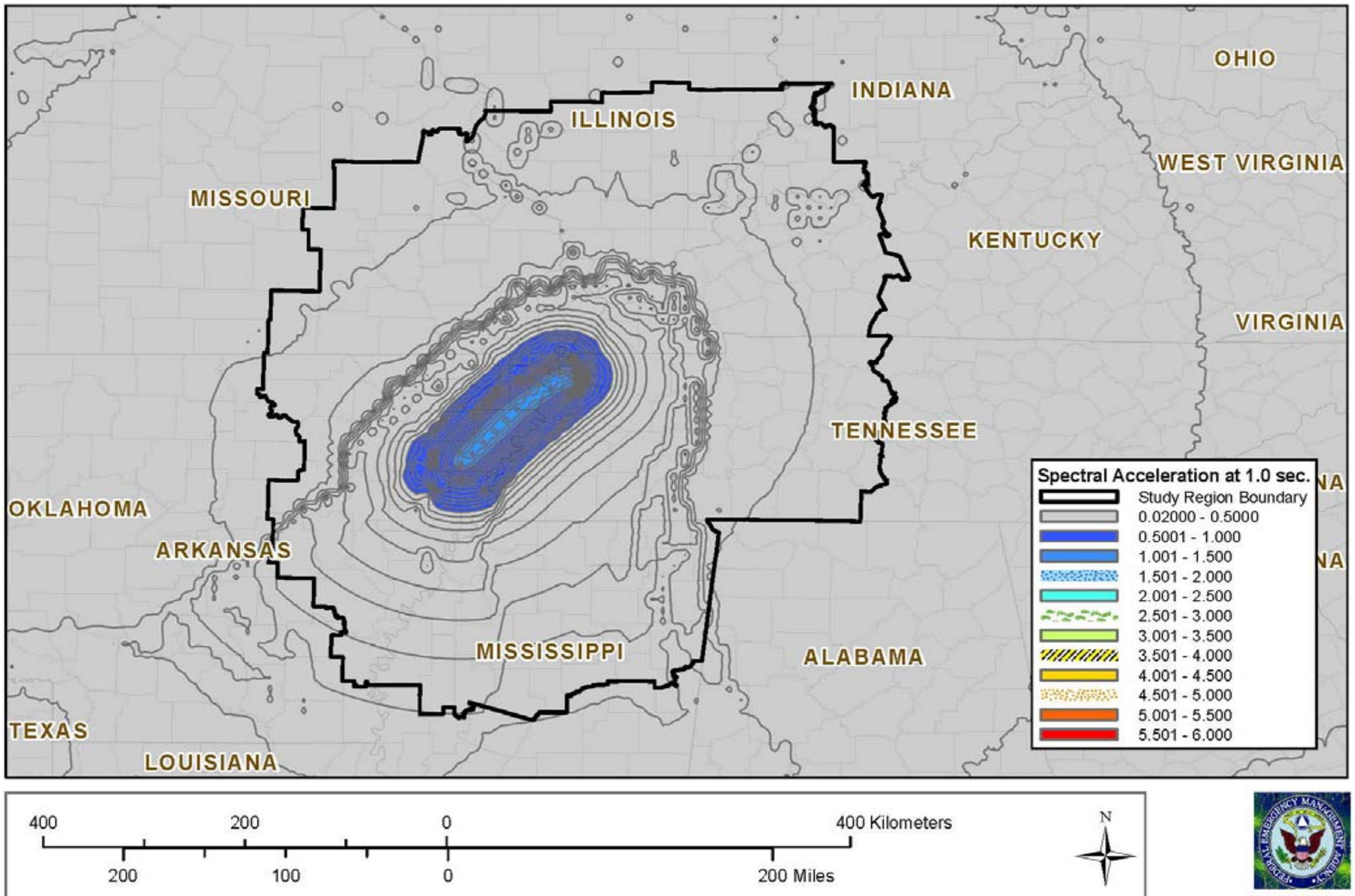


FEMA 1997-2003

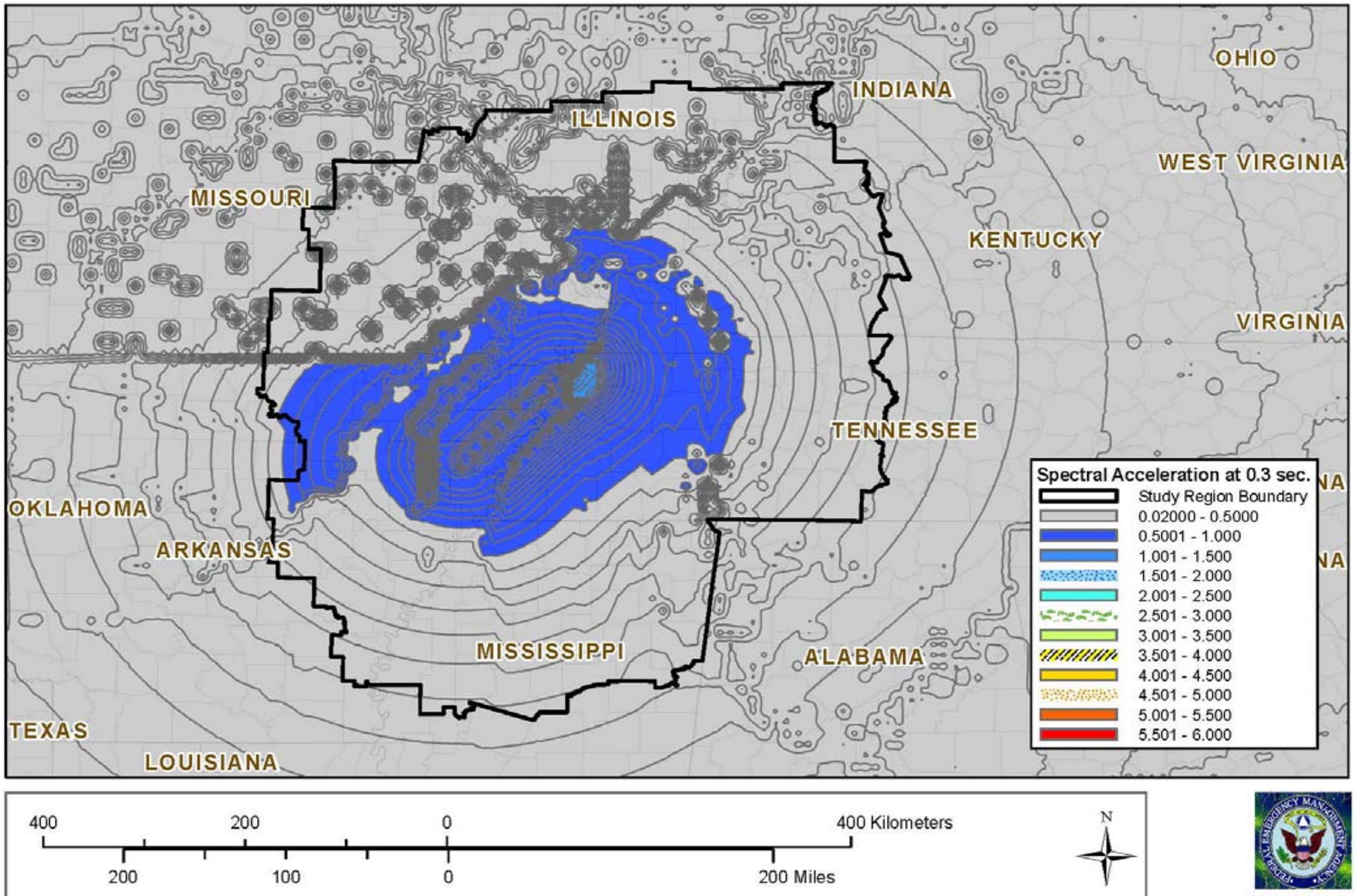
Peak Ground Acceleration
Study Region: SW Fault 1
Hazard Scenario: 16 December 1811 (New Madrid SW) Fault, M7.7



Spectral Acceleration at 1.0 sec.
Study Region: SW Fault 1
Hazard Scenario: 16 December 1811 (New Madrid SW) Fault, M7.7



Spectral Acceleration at 0.3 sec.
Study Region: SW Fault 1
Hazard Scenario: 16 December 1811 (New Madrid SW) Fault, M7.7



APPENDIX E: EXAMPLE HAZUS GLOBAL SUMMARY REPORT

The Hazus Global Summary Report for Scenario A 4028 81 10 is included hereafter as an example of the type of information summarized in each Global Summary Report. Due to the length of each report, all other Global Summary Reports are not included in this appendix but are linked as electronic files for individual download. See List of Files, page vii, for links.

Hazus-MH: Earthquake Event Report

Region Name: CC A 4028 81 10 H

Earthquake Scenario: A 4028 81 10

Print Date: January 04, 2014

Totals only reflect data for those census tracts/blocks included in the user's study region.

Disclaimer:
The estimates of social and economic impacts contained in this report were produced using Hazus loss estimation methodology software which is based on current scientific and engineering knowledge. There are uncertainties inherent in any loss estimation technique. Therefore, there may be significant differences between the modeled results contained in this report and the actual social and economic losses following a specific earthquake. These results can be improved by using enhanced inventory, geotechnical, and observed ground motion data.

Table of Contents

General Description of the Region

Hazus is a regional earthquake loss estimation model that was developed by the Federal Emergency Management Agency and the National Institute of Building Sciences. The primary purpose of Hazus is to provide a methodology and software application to develop earthquake losses at a regional scale. These loss estimates would be used primarily by local, state and regional officials to plan and stimulate efforts to reduce risks from earthquakes and to prepare for emergency response and recovery.

The earthquake loss estimates provided in this report was based on a region that includes 178 county(ies) from the following state(s):

Arkansas

Illinois

Indiana

Kentucky

Mississippi

Missouri

Tennessee

Note:
Appendix A contains a complete listing of the counties contained in the region.

The geographical size of the region is 93,381.73 square miles and contains 1,616 census tracts. There are over 2,634 thousand households in the region which has a total population of 6,841,567 people (2002 Census Bureau data). The distribution of population by State and County is provided in Appendix B.

There are an estimated 3,106 thousand buildings in the region with a total building replacement value (excluding contents) of 465,317 (millions of dollars). Approximately 93.00 % of the buildings (and 73.00% of the building value) are associated with residential housing.

The replacement value of the transportation and utility lifeline systems is estimated to be 175,190 and 85,293 (millions of dollars) , respectively.

Building and Lifeline Inventory

Building Inventory

Hazus estimates that there are 3,106 thousand buildings in the region which have an aggregate total replacement value of 465,317 (millions of dollars) . Appendix B provides a general distribution of the building value by State and County.

In terms of building construction types found in the region, wood frame construction makes up 70% of the building inventory. The remaining percentage is distributed between the other general building types.

Critical Facility Inventory

Hazus breaks critical facilities into two (2) groups: essential facilities and high potential loss facilities (HPL). Essential facilities include hospitals, medical clinics, schools, fire stations, police stations and emergency operations facilities. High potential loss facilities include dams, levees, military installations, nuclear power plants and hazardous material sites.

For essential facilities, there are 205 hospitals in the region with a total bed capacity of 28,763 beds. There are 3,202 schools, 1,183 fire stations, 818 police stations and 63 emergency operation facilities. With respect to high potential loss facilities (HPL), there are 3,776 dams identified within the region. Of these, 608 of the dams are classified as 'high hazard'. The inventory also includes 3,593 hazardous material sites, 0 military installations and 0 nuclear power plants.

Transportation and Utility Lifeline Inventory

Within Hazus, the lifeline inventory is divided between transportation and utility lifeline systems. There are seven (7) transportation systems that include highways, railways, light rail, bus, ports, ferry and airports. There are six (6) utility systems that include potable water, wastewater, natural gas, crude & refined oil, electric power and communications. The lifeline inventory data are provided in Tables 1 and 2.

The total value of the lifeline inventory is over 260,483.00 (millions of dollars). This inventory includes over 28,725 kilometers of highways, 21,414 bridges, 713,176 kilometers of pipes.

Table 1: Transportation System Lifeline Inventory

System	Component	# Locations/ # Segments	Replacement value (millions of dollars)
Highway	Bridges	21,414	16,825.20
	Segments	5,662	136,235.00
	Tunnels	0	0.00
		Subtotal	**153,060.20**
Railways	Bridges	282	36.60
	Facilities	100	266.30
	Segments	6,501	11,451.20
	Tunnels	0	0.00
		Subtotal	**11,754.00**
Light Rail	Bridges	0	0.00
	Facilities	37	98.50
	Segments	36	39.90
	Tunnels	0	0.00
		Subtotal	**138.50**
Bus	Facilities	56	59.40
		Subtotal	**59.40**
Ferry	Facilities	18	24.00
		Subtotal	**24.00**
Port	Facilities	540	1,078.40
		Subtotal	**1,078.40**
Airport	Facilities	150	1,597.70
	Runways	197	7,478.90
		Subtotal	**9,076.60**
		Total	**175,190.90**

Table 2: Utility System Lifeline Inventory

System	Component	# Locations / Segments	Replacement value (millions of dollars)
Potable Water	Distribution Lines	NA	7,131.80
	Facilities	163	5,395.90
	Pipelines	0	0.00
		Subtotal	**12,527.70**
Waste Water	Distribution Lines	NA	4,279.10
	Facilities	1,072	69,056.90
	Pipelines	0	0.00
		Subtotal	**73,335.90**
Natural Gas	Distribution Lines	NA	2,852.70
	Facilities	94	96.10
	Pipelines	0	0.00
		Subtotal	**2,948.80**
Oil Systems	Facilities	29	2.70
	Pipelines	0	0.00
		Subtotal	**2.70**
Electrical Power	Facilities	100	10,678.80
		Subtotal	**10,678.80**
Communication	Facilities	671	63.20
		Subtotal	**63.20**
		Total	**99,557.10**

Earthquake Scenario

Hazus uses the following set of information to define the earthquake parameters used for the earthquake loss estimate provided in this report.

Scenario Name	A 4028 81 10
Type of Earthquake	Historical
Fault Name	NA
Historical Epicenter ID #	4028
Probabilistic Return Period	NA
Longitude of Epicenter	-89.60
Latitude of Epicenter	36.50
Earthquake Magnitude	8.10
Depth (Km)	10.00
Rupture Length (Km)	NA
Rupture Orientation (degrees)	NA
Attenuation Function	Atkinson and Boore (2006)

Building Damage

Hazus estimates that about 1,560,147 buildings will be at least moderately damaged. This is over 50.00 % of the buildings in the region. There are an estimated 547,929 buildings that will be damaged beyond repair. The definition of the 'damage states' is provided in Volume 1: Chapter 5 of the Hazus technical manual. Table 3 below summarizes the expected damage by general occupancy for the buildings in the region. Table 4 below summarizes the expected damage by general building type.

Table 3: Expected Building Damage by Occupancy

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Agriculture	1,107	0.13	930	0.14	2,167	0.33	3,345	0.94	10,046	1.83
Commercial	9,254	1.08	9,315	1.36	21,753	3.32	29,799	8.36	74,724	13.64
Education	481	0.06	377	0.05	714	0.11	959	0.27	2,362	0.43
Government	389	0.05	357	0.05	822	0.13	1,306	0.37	3,224	0.59
Industrial	2,098	0.24	2,114	0.31	5,265	0.80	7,986	2.24	21,645	3.95
Other Residential	157,454	18.32	130,115	18.93	145,554	22.19	122,928	34.49	246,463	44.98
Religion	3,101	0.36	2,400	0.35	2,843	0.43	2,500	0.70	6,684	1.22
Single Family	685,764	79.77	541,578	78.81	476,722	72.69	187,554	52.63	182,782	33.36
Total	**859,649**		**687,187**		**655,841**		**356,376**		**547,930**	

Table 4: Expected Building Damage by Building Type (All Design Levels)

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Wood	782,271	91.00	617286	89.83	528,821	80.63	183,820	51.58	76,332	13.93
Steel	747	0.09	896	0.13	4,984	0.76	13,635	3.83	48,949	8.93
Concrete	473	0.06	611	0.09	2,391	0.36	4,843	1.36	12,577	2.30
Precast	871	0.10	671	0.10	2,131	0.32	3,440	0.97	11,380	2.08
RM	1,119	0.13	608	0.09	1,857	0.28	2,924	0.82	7,054	1.29
URM	61,587	7.16	48677	7.08	70,040	10.68	69,802	19.59	209,357	38.21
MH	12,580	1.46	18437	2.68	45,617	6.96	77,914	21.86	182,280	33.27
Total	**859,649**		**687,187**		**655,841**		**356,376**		**547,930**	

*Note:

RM	Reinforced Masonry
URM	Unreinforced Masonry
MH	Manufactured Housing

Essential Facility Damage

Before the earthquake, the region had 28,763 hospital beds available for use. On the day of the earthquake, the model estimates that only 715 hospital beds (2.00%) are available for use by patients already in the hospital and those injured by the earthquake. After one week, 6.00% of the beds will be back in service. By 30 days, 17.00% will be operational.

Table 5: Expected Damage to Essential Facilities

		# Facilities		
Classification	Total	At Least Moderate Damage > 50%	Complete Damage > 50%	With Functionality > 50% on day 1
Hospitals	205	201	151	2
Schools	3,202	3,137	2,578	23
EOCs	63	62	51	0
PoliceStations	818	796	667	6
FireStations	1,183	1,146	989	10

Transportation and Utility Lifeline Damage

Table 6 provides damage estimates for the transportation system.

Table 6: Expected Damage to the Transportation Systems

System	Component	Number of Locations				
		Locations/ Segments	With at Least Mod. Damage	With Complete Damage	With Functionality > 50 %	
					After Day 1	After Day 7
Highway	Segments	5,662	0	0	5,662	5,662
	Bridges	21,414	11,482	4,368	10,109	13,676
	Tunnels	0	0	0	0	0
Railways	Segments	6,501	0	0	6,501	6,501
	Bridges	282	107	2	176	278
	Tunnels	0	0	0	0	0
	Facilities	100	2	0	100	100
Light Rail	Segments	36	0	0	36	36
	Bridges	0	0	0	0	0
	Tunnels	0	0	0	0	0
	Facilities	37	0	0	37	37
Bus	Facilities	56	2	0	55	56
Ferry	Facilities	18	2	0	18	18
Port	Facilities	540	35	13	517	527
Airport	Facilities	150	7	1	148	149
	Runways	197	0	0	197	197

Note: Roadway segments, railroad tracks and light rail tracks are assumed to be damaged by ground failure only. If ground failure maps are not provided, damage estimates to these components will not be computed.

Tables 7-9 provide information on the damage to the utility lifeline systems. Table 7 provides damage to the utility system facilities. Table 8 provides estimates on the number of leaks and breaks by the pipelines of the utility systems. For electric power and potable water, Hazus performs a simplified system performance analysis. Table 9 provides a summary of the system performance information.

Table 7 : Expected Utility System Facility Damage

System	# of Locations				
	Total #	With at Least Moderate Damage	With Complete Damage	with Functionality > 50 % After Day 1	with Functionality > 50 % After Day 7
Potable Water	163	27	1	89	161
Waste Water	1,072	124	6	340	1,059
Natural Gas	94	8	0	73	94
Oil Systems	29	3	0	15	29
Electrical Power	100	9	1	50	99
Communication	671	100	2	664	669

Table 8 : Expected Utility System Pipeline Damage (Site Specific)

System	Total Pipelines Length (kms)	Number of Leaks	Number of Breaks
Potable Water	356,588	443855	110964
Waste Water	213,953	222960	55740
Natural Gas	142,635	76384	19096
Oil	0	0	0

Table 9: Expected Potable Water and Electric Power System Performance

	Total # of Households	Number of Households without Service				
		At Day 1	At Day 3	At Day 7	At Day 30	At Day 90
Potable Water	2,634,125	1,834,583	1,687,318	1,410,879	616,237	229,429
Electric Power		58,212	38,372	18,678	5,330	72

Induced Earthquake Damage

Fire Following Earthquake

Fires often occur after an earthquake. Because of the number of fires and the lack of water to fight the fires, they can often burn out of control. Hazus uses a Monte Carlo simulation model to estimate the number of ignitions and the amount of burnt area. For this scenario, the model estimates that there will be 1 ignitions that will burn about 0.01 sq. mi 0.00 % of the region's total area.) The model also estimates that the fires will displace about 37 people and burn about 2 (millions of dollars) of building value.

Debris Generation

Hazus estimates the amount of debris that will be generated by the earthquake. The model breaks the debris into two general categories: a) Brick/Wood and b) Reinforced Concrete/Steel. This distinction is made because of the different types of material handling equipment required to handle the debris.

The model estimates that a total of 107.74 million tons of debris will be generated. Of the total amount, Brick/Wood comprises 39.00% of the total, with the remainder being Reinforced Concrete/Steel. If the debris tonnage is converted to an estimated number of truckloads, it will require 4,309,680 truckloads (@25 tons/truck) to remove the debris generated by the earthquake.

Social Impact

Shelter Requirement

Hazus estimates the number of households that are expected to be displaced from their homes due to the earthquake and the number of displaced people that will require accommodations in temporary public shelters. The model estimates 287,406 households to be displaced due to the earthquake. Of these, 215,200 people (out of a total population of 6,841,567) will seek temporary shelter in public shelters.

Casualties

Hazus estimates the number of people that will be injured and killed by the earthquake. The casualties are broken down into four (4) severity levels that describe the extent of the injuries. The levels are described as follows;

- Severity Level 1: Injuries will require medical attention but hospitalization is not needed.
- Severity Level 2: Injuries will require hospitalization but are not considered life-threatening
- Severity Level 3: Injuries will require hospitalization and can become life threatening if not promptly treated.
- Severity Level 4: Victims are killed by the earthquake.

The casualty estimates are provided for three (3) times of day: 2:00 AM, 2:00 PM and 5:00 PM. These times represent the periods of the day that different sectors of the community are at their peak occupancy loads. The 2:00 AM estimate considers that the residential occupancy load is maximum, the 2:00 PM estimate considers that the educational, commercial and industrial sector loads are maximum and 5:00 PM represents peak commute time.

Table 10 provides a summary of the casualties estimated for this earthquake

Table 10: Casualty Estimates

		Level 1	Level 2	Level 3	Level 4
2 AM	Commercial	1,293	400	62	122
	Commuting	14	18	31	6
	Educational	0	0	0	0
	Hotels	1,427	441	71	139
	Industrial	1,817	568	89	174
	Other-Residential	42,798	12,081	1,470	2,786
	Single Family	60,681	17,207	2,495	4,886
	Total	**108,029**	**30,715**	**4,218**	**8,114**
2 PM	Commercial	86,830	26,893	4,207	8,192
	Commuting	124	161	276	53
	Educational	32,943	10,506	1,751	3,412
	Hotels	276	86	14	27
	Industrial	13,436	4,202	658	1,279
	Other-Residential	9,646	2,758	348	641
	Single Family	14,317	4,182	636	1,180
	Total	**157,571**	**48,788**	**7,891**	**14,784**
5 PM	Commercial	71,624	22,253	3,528	6,702
	Commuting	3,371	4,369	7,529	1,450
	Educational	3,429	1,095	182	356
	Hotels	427	132	21	42
	Industrial	8,397	2,626	411	799
	Other-Residential	16,182	4,636	591	1,091
	Single Family	24,494	7,140	1,087	2,017
	Total	**127,925**	**42,251**	**13,351**	**12,457**

Economic Loss

The total economic loss estimated for the earthquake is 232,230.61 (millions of dollars), which includes building and lifeline related losses based on the region's available inventory. The following three sections provide more detailed information about these losses.

Building-Related Losses

The building losses are broken into two categories: direct building losses and business interruption losses. The direct building losses are the estimated costs to repair or replace the damage caused to the building and its contents. The business interruption losses are the losses associated with inability to operate a business because of the damage sustained during the earthquake. Business interruption losses also include the temporary living expenses for those people displaced from their homes because of the earthquake.

The total building-related losses were 214,421.25 (millions of dollars); 22 % of the estimated losses were related to the business interruption of the region. By far, the largest loss was sustained by the residential occupancies which made up over 40 % of the total loss. Table 11 below provides a summary of the losses associated with the building damage.

Table 11: Building-Related Economic Loss Estimates

(Millions of dollars)

Category	Area	Single Family	Other Residential	Commercial	Industrial	Others	Total
Income Losses							
	Wage	0.00	690.58	9,233.17	483.15	771.21	11,178.10
	Capital-Related	0.00	292.82	7,505.50	302.99	202.64	8,303.95
	Rental	1,923.72	1,901.75	3,922.08	166.25	353.32	8,267.12
	Relocation	6,757.04	2,016.43	6,339.18	663.69	2,708.81	18,485.15
	Subtotal	**8,680.77**	**4,901.58**	**26,999.93**	**1,616.07**	**4,035.97**	**46,234.31**
Capital Stock Losses							
	Structural	9,773.18	4,397.71	10,066.32	2,615.24	3,172.03	30,024.48
	Non_Structural	31,450.88	16,959.87	31,926.24	10,684.23	9,186.20	100,207.43
	Content	6,369.99	3,467.66	14,714.54	6,795.42	4,264.43	35,612.04
	Inventory	0.00	0.00	556.22	1,663.55	123.22	2,342.99
	Subtotal	**47,594.05**	**24,825.25**	**57,263.33**	**21,758.44**	**16,745.87**	**168,186.94**
	Total	**56,274.81**	**29,726.83**	**84,263.26**	**23,374.51**	**20,781.84**	**214,421.25**

Transportation and Utility Lifeline Losses

For the transportation and utility lifeline systems, Hazus computes the direct repair cost for each component only. There are no losses computed by Hazus for business interruption due to lifeline outages. Tables 12 & 13 provide a detailed breakdown in the expected lifeline losses.

Hazus estimates the long-term economic impacts to the region for 15 years after the earthquake. The model quantifies this information in terms of income and employment changes within the region. Table 14 presents the results of the region for the given earthquake.

Table 12: Transportation System Economic Losses
(Millions of dollars)

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Highway	Segments	136,234.98	$0.00	0.00
	Bridges	16,825.18	$4084.32	24.28
	Tunnels	0.00	$0.00	0.00
	Subtotal	**153060.20**	**4,084.30**	
Railways	Segments	11,451.16	$0.00	0.00
	Bridges	36.56	$6.68	18.28
	Tunnels	0.00	$0.00	0.00
	Facilities	266.30	$53.03	19.92
	Subtotal	**11754.00**	**59.70**	
Light Rail	Segments	39.93	$0.00	0.00
	Bridges	0.00	$0.00	0.00
	Tunnels	0.00	$0.00	0.00
	Facilities	98.53	$21.11	21.42
	Subtotal	**138.50**	**21.10**	
Bus	Facilities	59.39	$11.98	20.17
	Subtotal	**59.40**	**12.00**	
Ferry	Facilities	23.96	$4.82	20.11
	Subtotal	**24.00**	**4.80**	
Port	Facilities	1,078.38	$229.19	21.25
	Subtotal	**1078.40**	**229.20**	
Airport	Facilities	1,597.65	$297.91	18.65
	Runways	7,478.91	$0.00	0.00
	Subtotal	**9076.60**	**297.90**	
	Total	**175190.90**	**4,709.00**	

Table 13: Utility System Economic Losses
(Millions of dollars)

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Potable Water	Pipelines	0.00	$0.00	0.00
	Facilities	5,395.90	$652.85	12.10
	Distribution Lines	7,131.80	$1,997.35	28.01
	Subtotal	**12,527.69**	**$2,650.20**	
Waste Water	Pipelines	0.00	$0.00	0.00
	Facilities	69,056.90	$7,956.69	11.52
	Distribution Lines	4,279.10	$1,003.32	23.45
	Subtotal	**73,335.93**	**$8,960.01**	
Natural Gas	Pipelines	0.00	$0.00	0.00
	Facilities	96.10	$7.94	8.27
	Distribution Lines	2,852.70	$343.73	12.05
	Subtotal	**2,948.77**	**$351.67**	
Oil Systems	Pipelines	0.00	$0.00	0.00
	Facilities	2.70	$0.27	9.68
	Subtotal	**2.75**	**$0.27**	
Electrical Power	Facilities	10,678.80	$1,131.31	10.59
	Subtotal	**10,678.80**	**$1,131.31**	
Communication	Facilities	63.20	$6.81	10.79
	Subtotal	**63.18**	**$6.81**	
	Total	**99,557.12**	**$13,100.27**	

Table 14. Indirect Economic Impact with outside aid
(Employment as # of people and Income in millions of $)

LOSS		Total	%

Appendix A: County Listing for the Region

Arkansas,AR

Clay,AR

Craighead,AR

Crittenden,AR

Cross,AR

Desha,AR

Fulton,AR

Greene,AR

Independence,AR

Izard,AR

Jackson,AR

Lawrence,AR

Lee,AR

Lonoke,AR

Mississippi,AR

Monroe,AR

Phillips,AR

Poinsett,AR

Prairie,AR

Randolph,AR

Saint Francis,AR

Sharp,AR

White,AR

Woodruff,AR

Alexander,IL

Clay,IL

Clinton,IL

Edwards,IL

Franklin,IL

Gallatin,IL

Hamilton,IL

Hardin,IL

Jackson,IL

Jefferson,IL

Johnson,IL

Lawrence,IL

Marion,IL

Massac,IL

Monroe,IL

Perry,IL

Pope,IL

Pulaski,IL

Randolph,IL

Richland,IL

Saint Clair,IL

Saline,IL

Union,IL

Wabash,IL

Washington,IL

Wayne,IL

White,IL

Williamson,IL

Gibson,IN

Knox,IN

Pike,IN

Posey,IN

Spencer,IN

Vanderburgh,IN

Warrick,IN

Ballard,KY

Butler,KY

Caldwell,KY

Calloway,KY

Carlisle,KY

Christian,KY

Crittenden,KY

Daviess,KY

Fulton,KY

Graves,KY

Hancock,KY

Henderson,KY

Hickman,KY

Hopkins,KY

Livingston,KY

Logan,KY

Lyon,KY

McCracken,KY

McLean,KY

Marshall,KY

Muhlenberg,KY

Ohio,KY

Todd,KY

Trigg,KY

Union,KY

Webster,KY

Alcorn,MS

Benton,MS

Bolivar,MS

Calhoun,MS

Carroll,MS

Chickasaw,MS

Clay,MS

Coahoma,MS

Desoto,MS

Grenada,MS

Itawamba,MS

Lafayette,MS

Lee,MS

Leflore,MS

Marshall,MS

Monroe,MS

Montgomery,MS

Panola,MS

Pontotoc,MS

Prentiss,MS

Quitman,MS

Sunflower,MS

Tallahatchie,MS

Tate,MS

Tippah,MS

Tishomingo,MS

Tunica,MS

Union,MS

Webster,MS

Yalobusha,MS

Bollinger,MO

Butler,MO

Cape Girardeau,MO

Carter,MO

Crawford,MO

Dent,MO

Dunklin,MO

Howell,MO

Iron,MO

Jefferson,MO

Madison,MO

Mississippi,MO

New Madrid,MO

Oregon,MO

Pemiscot,MO

Perry,MO

Reynolds,MO

Ripley,MO

Sainte Genevieve,MO

Saint Francois,MO

Scott,MO

Shannon,MO

Stoddard,MO

Washington,MO

Wayne,MO

Benton,TN

Carroll,TN

Cheatham,TN

Chester,TN

Crockett,TN

Davidson,TN

Decatur,TN

Dickson,TN

Dyer,TN

Fayette,TN

Gibson,TN

Giles,TN

Hardeman,TN

Hardin,TN

Haywood,TN

Henderson,TN

Henry,TN

Hickman,TN

Houston,TN

Humphreys,TN

Lake,TN

Lauderdale,TN

Lawrence,TN

Lewis,TN

McNairy,TN

Madison,TN

Marshall,TN

Maury,TN

Montgomery,TN

Obion,TN

Perry,TN

Robertson,TN

Shelby,TN

Stewart,TN

Tipton,TN

Wayne,TN

Weakley,TN

Williamson,TN

Appendix B: Regional Population and Building Value Data

State	County Name	Population	Building Value (millions of dollars)		
			Residential	Non-Residential	Total
Arkansas					
	Arkansas	20,749	1,136	364	1,501
	Clay	17,609	945	235	1,181
	Craighead	82,148	4,142	1,461	5,603
	Crittenden	50,866	2,533	601	3,135
	Cross	19,526	858	215	1,074
	Desha	15,341	671	221	893
	Fulton	11,642	582	95	677
	Greene	37,331	1,953	502	2,456
	Independence	34,233	1,759	627	2,386
	Izard	13,249	604	128	733
	Jackson	18,418	889	272	1,162
	Lawrence	17,774	869	206	1,075
	Lee	12,580	405	85	491
	Lonoke	52,828	2,917	524	3,442
	Mississippi	51,979	2,468	776	3,244
	Monroe	10,254	496	143	640
	Phillips	26,445	1,054	309	1,364
	Poinsett	25,614	1,166	446	1,612
	Prairie	9,539	548	81	629
	Randolph	18,195	869	165	1,035
	Saint Francis	29,329	1,193	358	1,551
	Sharp	17,119	934	190	1,125
	White	67,165	3,341	849	4,191
	Woodruff	8,741	415	99	515
Total State		**668,674**	**32,747**	**8,952**	**41,715**
Illinois					
	Alexander	9,590	397	116	513
	Clay	14,560	674	254	929
	Clinton	35,535	1,806	680	2,487
	Edwards	6,971	310	124	434
	Franklin	39,018	1,862	600	2,462
	Gallatin	6,445	276	86	363
	Hamilton	8,621	389	90	479
	Hardin	4,800	217	26	244
	Jackson	59,612	2,846	1,042	3,889
	Jefferson	40,045	1,894	723	2,617
	Johnson	12,878	499	146	645
	Lawrence	15,452	732	253	986
	Marion	41,691	2,021	769	2,791
	Massac	15,161	702	239	942
	Monroe	27,619	1,598	438	2,037
	Perry	23,094	1,044	383	1,427
	Pope	4,413	242	31	274
	Pulaski	7,348	297	114	411

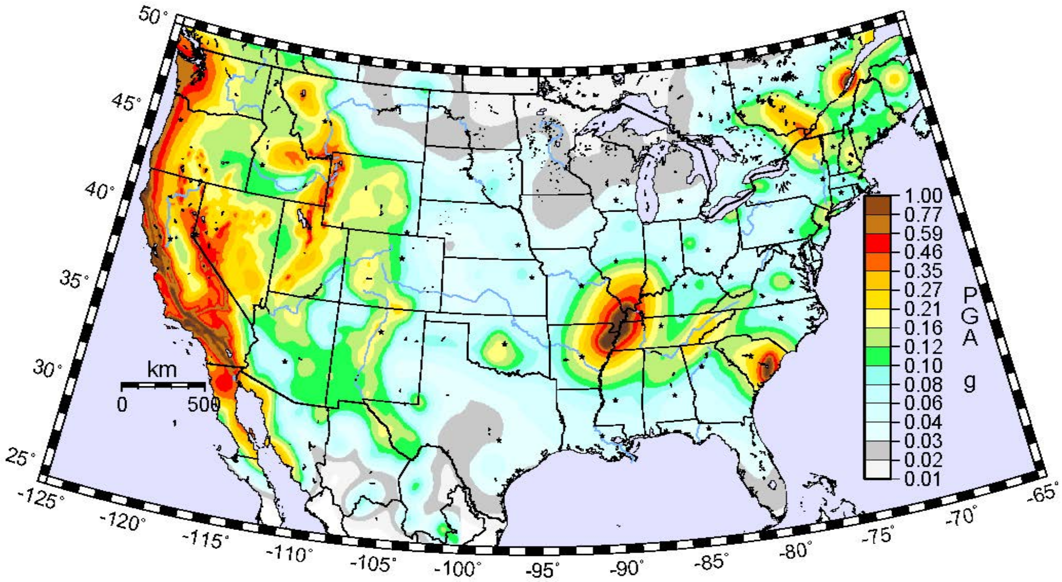
	Randolph	33,893	1,537	615	2,153
	Richland	16,149	819	416	1,235
	Saint Clair	256,082	13,337	4,087	17,424
	Saline	26,733	1,351	455	1,807
	Union	18,293	828	325	1,153
	Wabash	12,937	617	202	819
	Washington	15,148	848	382	1,231
	Wayne	17,151	769	267	1,036
	White	15,371	744	297	1,042
	Williamson	61,296	3,016	1,233	4,250
Total State		**845,906**	**41,672**	**14,393**	**56,080**
Indiana					
	Gibson	32,500	1,728	569	2,298
	Knox	39,256	2,096	938	3,035
	Pike	12,837	584	155	739
	Posey	27,061	1,471	414	1,885
	Spencer	20,391	1,024	427	1,451
	Vanderburgh	171,922	9,798	4,946	14,745
	Warrick	52,383	2,770	649	3,419
Total State		**356,350**	**19,471**	**8,098**	**27,572**
Kentucky					
	Ballard	8,286	418	142	560
	Butler	13,010	531	162	694
	Caldwell	13,060	658	234	892
	Calloway	34,177	1,640	641	2,281
	Carlisle	5,351	248	51	300
	Christian	72,265	3,530	1,238	4,769
	Crittenden	9,384	417	145	563
	Daviess	91,545	5,127	2,201	7,329
	Fulton	7,752	348	181	529
	Graves	37,028	1,645	653	2,298
	Hancock	8,392	415	148	563
	Henderson	44,829	2,444	1,022	3,467
	Hickman	5,262	254	90	344
	Hopkins	46,519	2,233	988	3,221
	Livingston	9,804	468	142	611
	Logan	26,573	1,232	658	1,890
	Lyon	8,080	499	105	605
	McCracken	65,514	3,772	1,928	5,701
	McLean	9,938	403	139	542
	Marshall	30,125	1,780	555	2,335
	Muhlenberg	31,839	1,310	457	1,768
	Ohio	22,916	946	315	1,262
	Todd	11,971	465	176	642
	Trigg	12,597	783	198	981
	Union	15,637	902	282	1,184
	Webster	14,120	672	232	904
Total State		**655,974**	**33,140**	**13,083**	**46,235**
Mississippi					
	Alcorn	34,558	1,488	726	2,215
	Benton	8,026	285	71	357

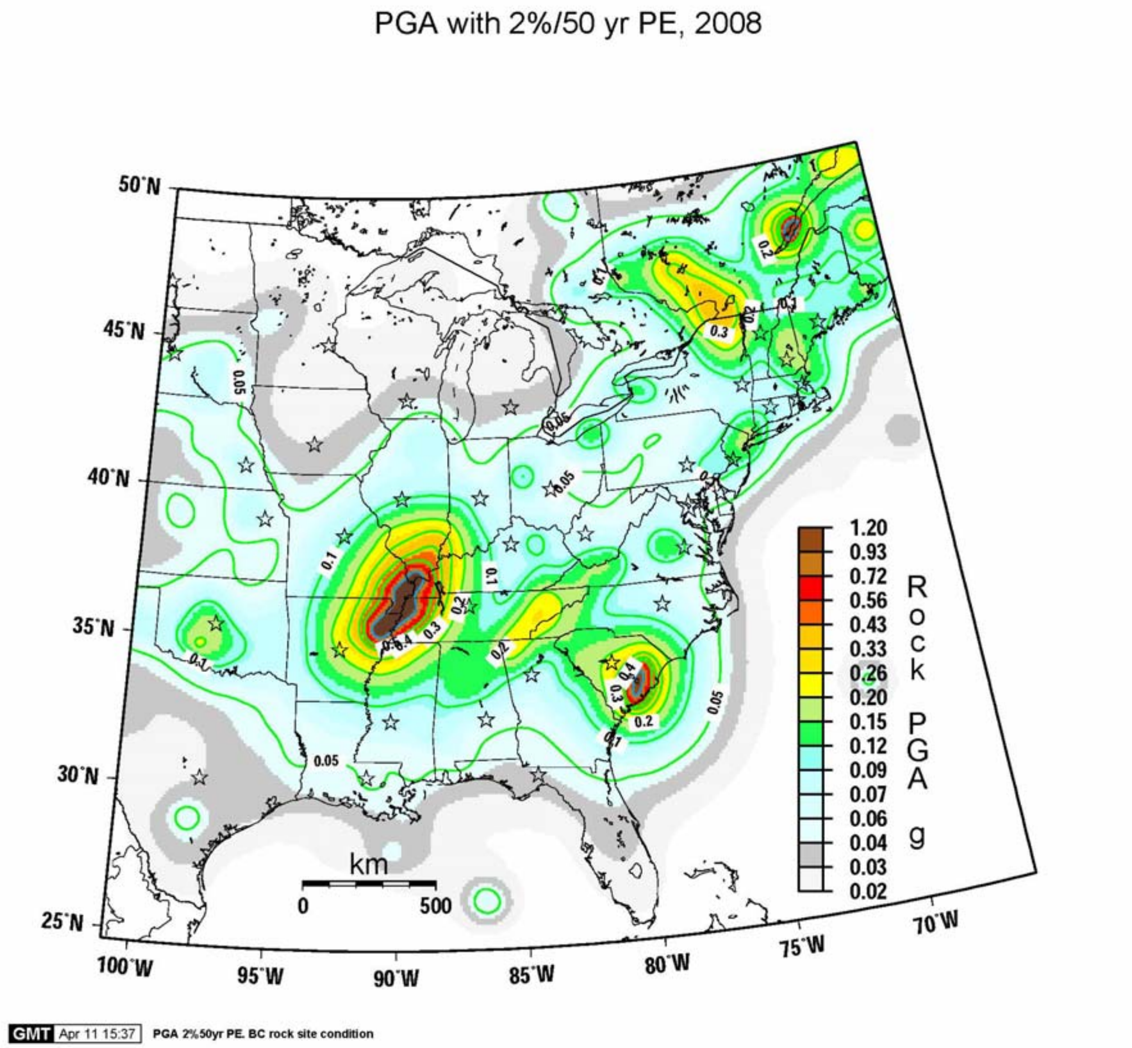
	Bolivar	40,633	1,319	509	1,829
	Calhoun	15,069	560	189	750
	Carroll	10,769	372	40	412
	Chickasaw	19,440	578	545	1,123
	Clay	21,979	739	309	1,048
	Coahoma	30,622	998	401	1,400
	Desoto	107,199	6,120	1,783	7,903
	Grenada	23,263	861	400	1,262
	Itawamba	22,770	914	363	1,278
	Lafayette	38,744	1,505	536	2,042
	Lee	75,755	3,165	2,041	5,207
	Leflore	37,947	1,286	698	1,984
	Marshall	34,993	1,204	387	1,592
	Monroe	38,014	1,420	596	2,017
	Montgomery	12,189	438	148	587
	Panola	34,274	1,010	383	1,393
	Pontotoc	26,726	918	399	1,317
	Prentiss	25,556	902	390	1,292
	Quitman	10,117	263	100	364
	Sunflower	34,369	897	354	1,252
	Tallahatchie	14,903	347	99	446
	Tate	25,370	911	260	1,171
	Tippah	20,826	828	340	1,168
	Tishomingo	19,163	884	312	1,196
	Tunica	9,227	302	177	480
	Union	25,362	912	381	1,293
	Webster	10,294	357	128	485
	Yalobusha	13,051	432	189	621
Total State		**841,208**	**32,215**	**13,254**	**45,484**
Missouri					
	Bollinger	12,029	450	84	535
	Butler	40,867	1,502	649	2,151
	Cape Girardeau	68,693	3,544	1,593	5,137
	Carter	5,941	239	64	304
	Crawford	22,804	1,050	323	1,373
	Dent	14,927	594	200	794
	Dunklin	33,155	1,112	490	1,602
	Howell	37,238	1,299	601	1,901
	Iron	10,697	432	123	555
	Jefferson	198,099	9,986	2,474	12,461
	Madison	11,800	474	181	656
	Mississippi	13,427	529	167	697
	New Madrid	19,760	728	265	993
	Oregon	10,344	355	103	459
	Pemiscot	20,047	664	238	903
	Perry	18,132	880	453	1,334
	Reynolds	6,689	324	69	394
	Ripley	13,509	442	151	593
	Sainte Genevieve	17,842	922	324	1,246
	Saint Francois	55,641	2,477	999	3,476
	Scott	40,422	1,649	797	2,446

	Shannon	8,324	293	59	353
	Stoddard	29,705	1,161	450	1,612
	Washington	23,344	753	168	921
	Wayne	13,259	563	139	703
Total State		**746,695**	**32,422**	**11,164**	**43,599**
Tennessee					
	Benton	16,537	701	230	932
	Carroll	29,475	1,174	388	1,562
	Cheatham	35,912	1,894	475	2,370
	Chester	15,540	657	179	837
	Crockett	14,532	617	194	811
	Davidson	569,891	34,569	15,940	50,509
	Decatur	11,731	518	177	695
	Dickson	43,156	2,235	716	2,952
	Dyer	37,279	1,749	944	2,694
	Fayette	28,806	1,430	616	2,047
	Gibson	48,152	2,064	1,077	3,141
	Giles	29,447	1,482	511	1,994
	Hardeman	28,105	1,021	368	1,389
	Hardin	25,578	1,076	432	1,509
	Haywood	19,797	720	359	1,079
	Henderson	25,522	1,027	448	1,475
	Henry	31,115	1,373	561	1,935
	Hickman	22,295	826	268	1,095
	Houston	8,088	353	77	430
	Humphreys	17,929	927	251	1,179
	Lake	7,954	281	68	349
	Lauderdale	27,101	974	360	1,335
	Lawrence	39,926	1,547	542	2,090
	Lewis	11,367	454	173	627
	McNairy	24,653	1,038	450	1,488
	Madison	91,837	4,604	2,126	6,730
	Marshall	26,767	1,306	501	1,808
	Maury	69,498	3,631	1,276	4,908
	Montgomery	134,768	6,935	1,993	8,928
	Obion	32,450	1,454	665	2,119
	Perry	7,631	340	88	429
	Robertson	54,433	2,929	947	3,876
	Shelby	897,472	51,004	19,353	70,358
	Stewart	12,370	637	146	783
	Tipton	51,271	2,407	585	2,992
	Wayne	16,842	485	226	712
	Weakley	34,895	1,391	462	1,853
	Williamson	126,638	9,471	3,057	12,528
Total State		**2,726,760**	**147,301**	**57,229**	**204,548**
Total Region		**6,841,567**	**338,968**	**126,173**	**465,233**

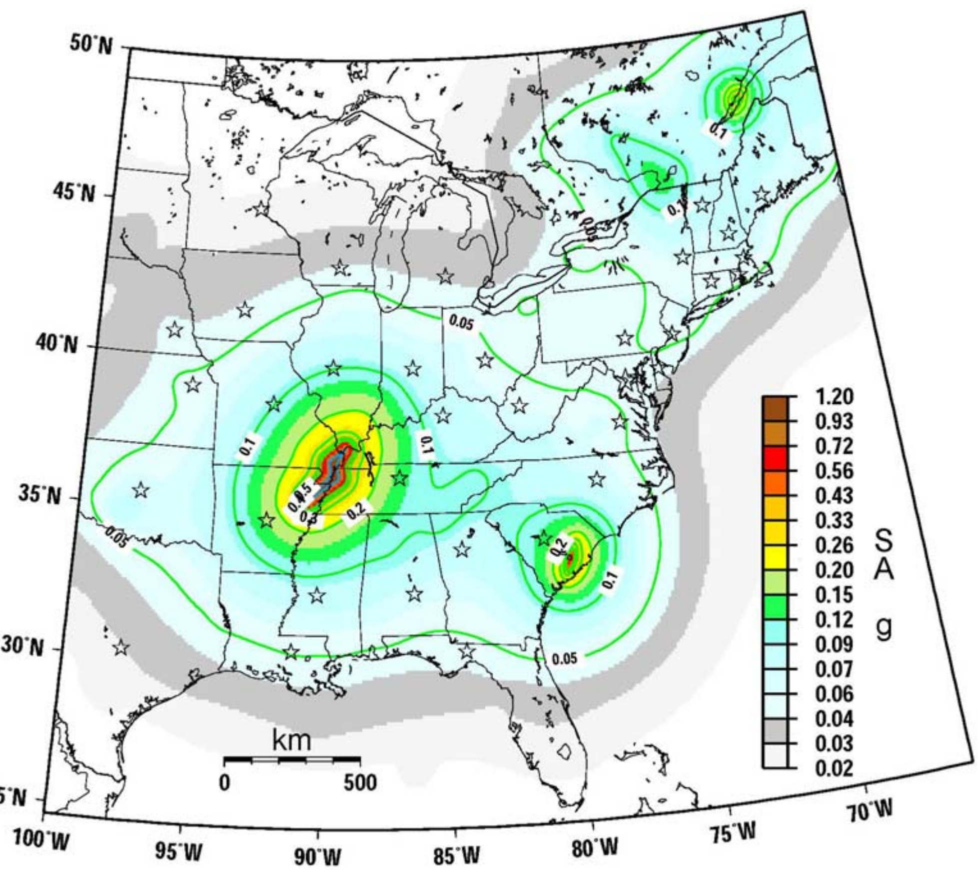
APPENDIX F: SELECTED NATIONAL SEISMIC HAZARD MAPS

PGA with 2% in 50 year PE. BC rock. 2008 USGS

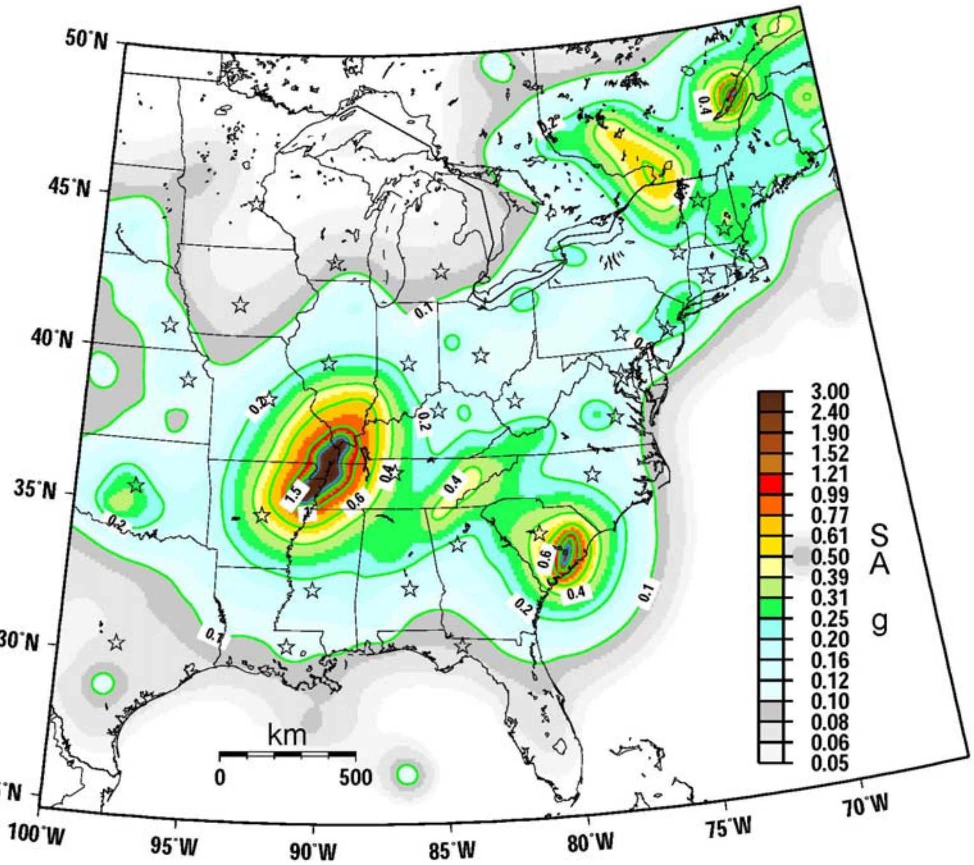


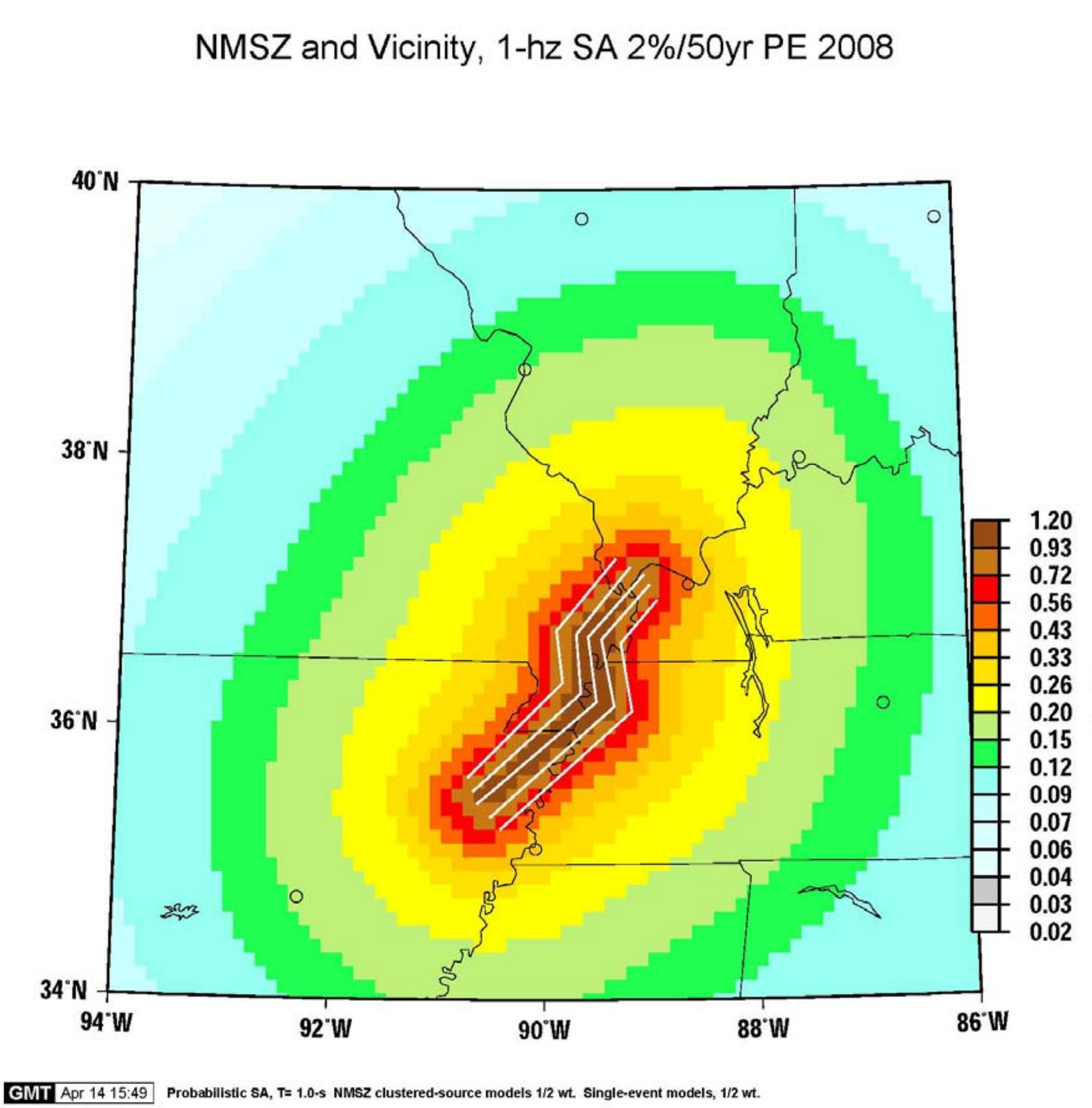

PGA with 2%/50 yr PE, 2008
50°N
45°N
40°N
35°N
30°N
25°N
100°W
95°W
90°W
85°W
80°W
75°W
70°W
km
0
500
1.20
0.93
0.72
0.56
0.43
0.33
0.26
0.20
0.15
0.12
0.09
0.07
0.06
0.04
0.03
0.02
Rock PGA g
GMT Apr 11 15:37 PGA 2%50yr PE. BC rock site condition

SA 1s 2%50yr PE, 2008



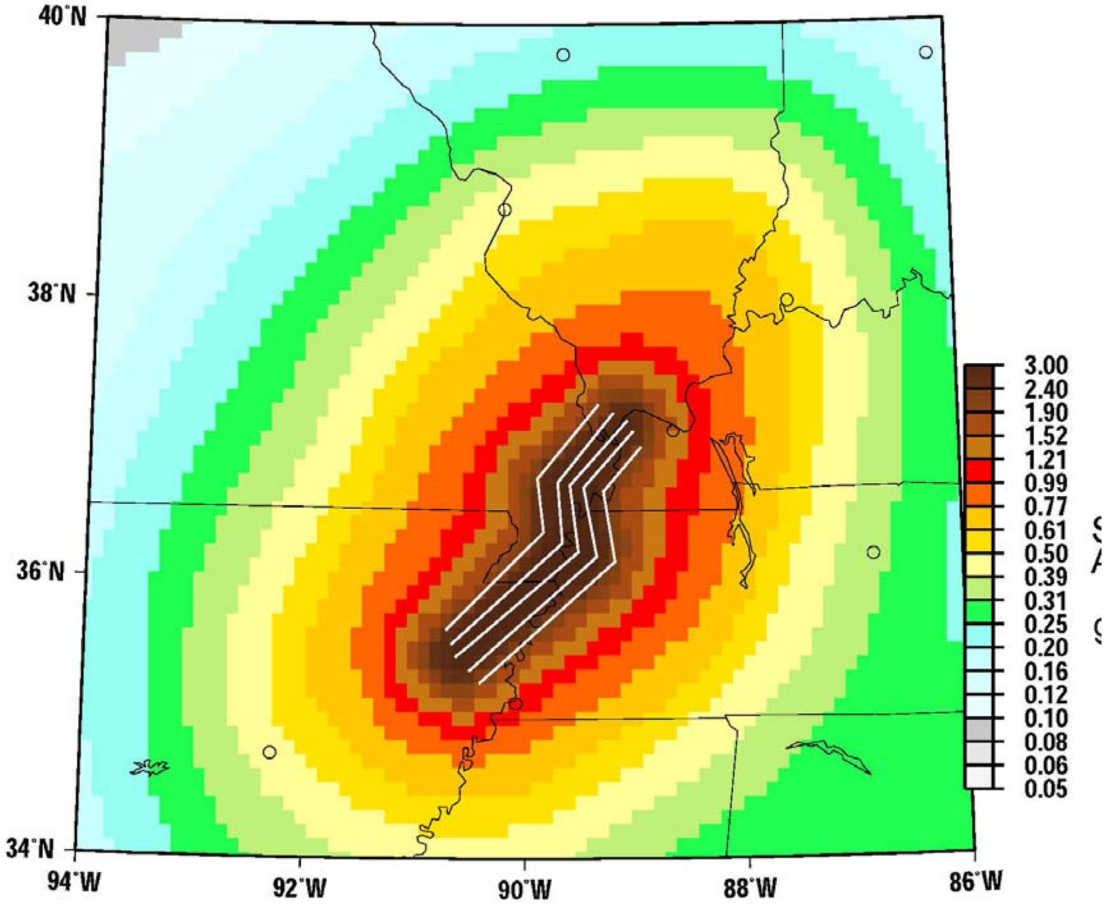
SA 0.2-s 2%/50year PE, 2008



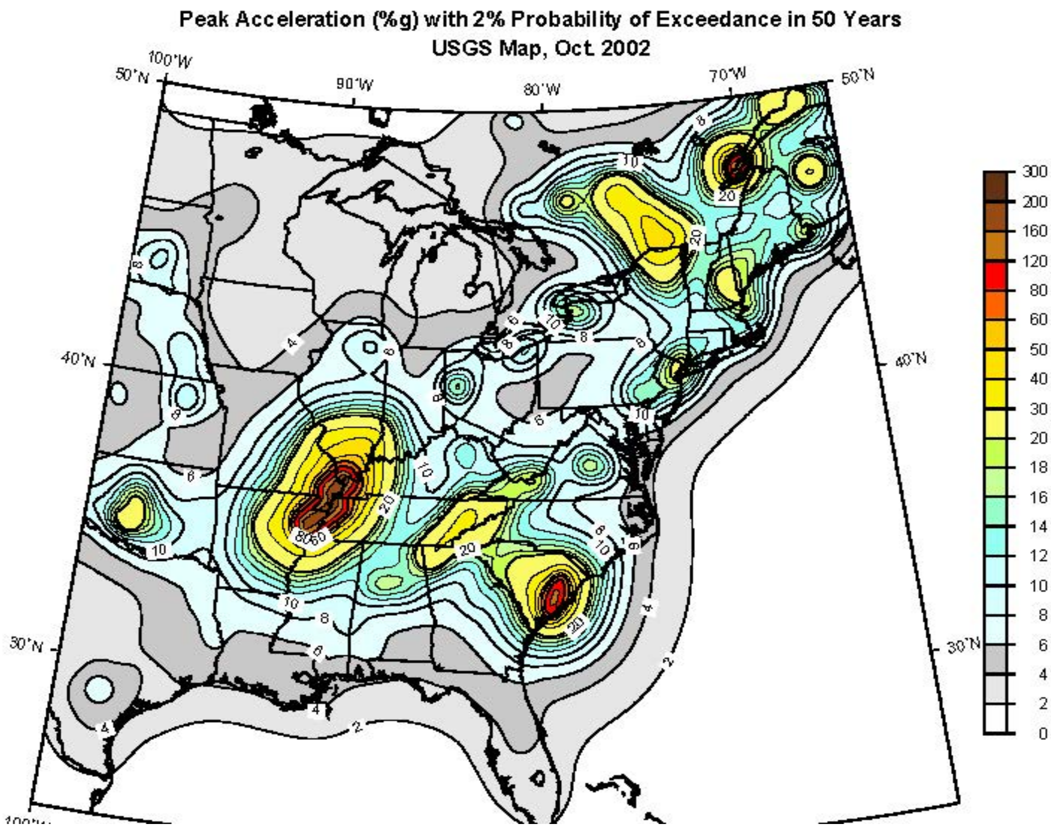


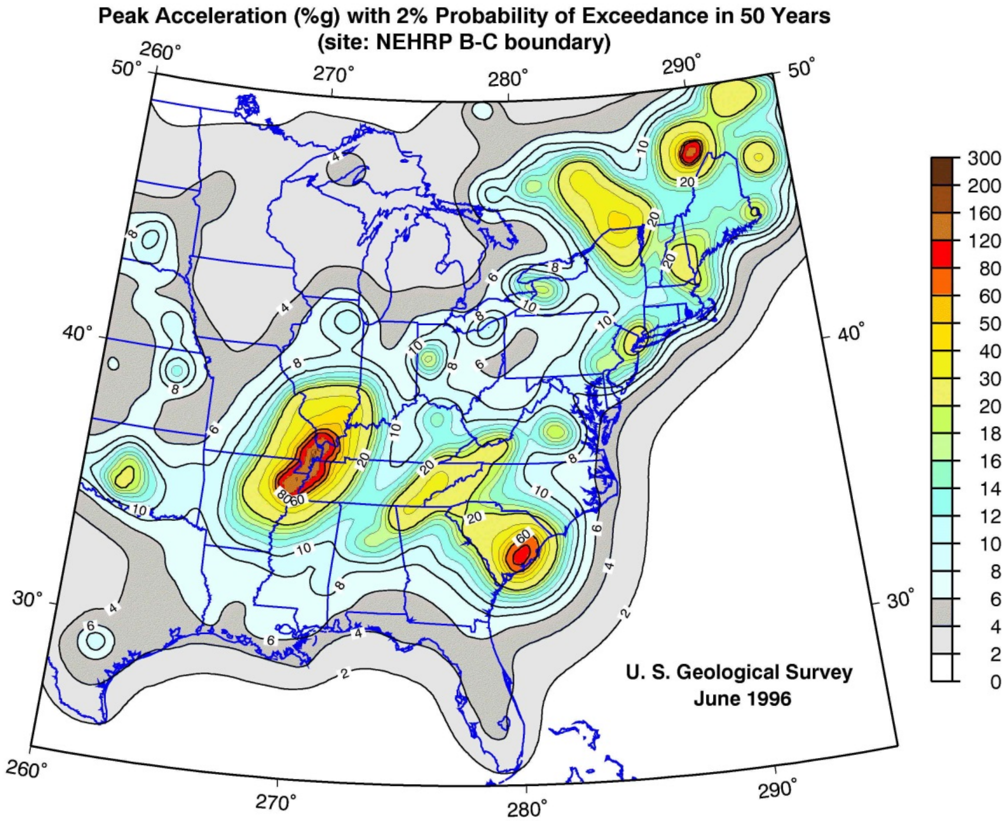
NMSZ and Vicinity, 1-hz SA 2%/50yr PE 2008
40°N
38°N
36°N
34°N
94°W
92°W
90°W
88°W
86°W
1.20
0.93
0.72
0.56
0.43
0.33
0.26
0.20
0.15
0.12
0.09
0.07
0.06
0.04
0.03
0.02
GMT Apr 14 15:49 Probabilistic SA, T= 1.0-s NMSZ clustered-source models 1/2 wt. Single-event models, 1/2 wt.

NMSZ and Vicinity, 5-hz SA 2%/50yr PE 2008



Probabilistic SA, T= 0.2-s NMSZ clustered-source models 1/2 wt. Firm rock site condition. White lines virtual fault locations.


Peak Acceleration (%g) with 2% Probability of Exceedance in 50 Years
USGS Map, Oct. 2002
100°W
90°W
80°W
70°W
50°N
40°N
30°N
300
200
160
120
80
60
50
40
30
20
18
16
14
12
10
8
6
4
2
0


Peak Acceleration (%g) with 2% Probability of Exceedance in 50 Years
(site: NEHRP B-C boundary)
U. S. Geological Survey
June 1996
300
200
160
120
80
60
50
40
30
20
18
16
14
12
10
8
6
4
2
0

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