New Madrid Seismic Zone
Catastrophic Earthquake Response Planning

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Lisa Johanna Cleveland, Lead Researcher
Amr S. Elnashai, Project Principal Investigator

Omar Pineda, Project Manager

Mid-America Earthquake Center
University of Illinois at Urbana-Champaign, Illinois, USA

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Executive Summary

The New Madrid seismic zone in the Central USA has experienced some of the strongest earthquake ground motions observed nationwide. The historic series of three earthquakes during 1811 and 1812 shook this Midwest region with magnitudes around 8. The earthquakes were extensively reported. However, limited damage occurred because of the area was sparsely populated. A recurrence of the 1811 and 1812 earthquakes would cause widespread and severely impacts affecting over 45 million residents of the states surrounding the New Madrid seismic zone. A repeat of these historical events would subject the major urban center of Memphis, Tennessee to intense ground shaking while other urban centers such as St. Louis, Missouri, would experience less intense shaking. This does not indicate that St. Louis is less vulnerable, however. Though not undertaken in this report, subsequent work will include the examination of other hazard scenario within the region of interest. These scenarios will represent seismic activity in the Wabash Valley Seismic Zone of M7.1 as well as near St. Louis, Missouri, of M6.0.

Numerous infrastructure systems are affected by regional ground shaking and failure. Buildings, transportation and utility networks would be damaged in addition to potentially serious loss of human life and crippling business interruptions. A new catastrophic planning effort is now underway in the Mid-America Earthquake (MAE) Center, in cooperation with the Institute of Crisis, Disaster and Risk Management of George Washington University, under the auspices of FEMA. The scope of the recently-started project is to quantify to the highest level of reliability possible the impact of a repeat of the New Madrid earthquakes on all societal endeavors. The outcome is intended for use in articulating response and recovery plans in order to reduce the anticipated disruption.

In this report, a preliminary analysis of 230 counties surrounding the New Madrid Fault is presented. Several levels of analysis using HAZUS-MH MR2 are undertaken; Level I, Improved Level I and Level II analyses. The HAZUS Level I analysis is the most basic and employs all default settings without any input from the user. The Improved Level I analysis applies ground motion with considerations for local site affects while still applying the default inventory and infrastructure component fragilities. The Level II analysis examines three parameters; liquefaction susceptibility, pipelines inventory and building fragilities. These parameterized fragilities were developed by the MAE Center for Memphis, Tennessee and adjusted to fit the region of interest in this study. Liquefaction susceptibility uses the same ground motion employed in the Improved Level I analysis and determines site liquefaction probabilities and ground deformation values to provide a more accurate hazard characterization. Pipeline data obtained from the Homeland Security Infrastructure Program (HSIP) Gold dataset for natural gas and oil pipelines are used in stead of the HAZUS pipeline assumption. Lastly, improved fragility relationships are employed with no changes of the building inventory. All three analysis sets (improved hazard, improved pipeline inventory and improved building fragilities) are compared to determine a range of impact values. The preliminary analyses are intended to (i) provide a baseline against more advanced analysis is compared, (ii) test the HAZUS

software for large region analysis and (iii) underline the importance of parameter variations and sensitivity analysis, as opposed to single analysis scenarios.

The Level II analysis that employs liquefaction susceptibility results in the highest estimate of economic losses and social impacts. The building stock experiences significant collapse rates, especially unreinforced masonry buildings and mobile homes. Hospitals, fire and police stations near the source are likely to incur heavy damage that will result in severe impairment of their function. Transportation and utility networks will be severely damaged thus hampering evacuation and the arrival of relief workers. The availability of potable water and electricity will reduced to a critical level. Finally, social and economic impacts will be severe. Human fatalities are likely to be between 1,500 and 2,000, depending on the location of the source. Furthermore regional losses can be expected to reach $43-$51 billion. The current Level II results are summarized in the table below. Based on the results of this study thus far, an earthquake on the southwest extension of the New Madrid fault system is likely to result in the most severe impact on the eight states in the Central and Eastern USA.

	Northeast	Central	Southwest
Fatalities	1,799	1,570	1,939
Buildings Losses	$32.9	$28.7	$34.4
Transportation Losses	$4.4	$4.4	$5.1
Utility Losses	$11.6	$9.8	$11.0
Total Direct Economic Losses	$48.9	$42.9	$50.5

The MAE Center-George Washington University team is continuing with the refinement of the impact assessment of the 8 states under consideration. The improvements entail updated hazard characterization for several scenario earthquakes, significant improvement in the inventory, especially for utilities and emergency services, and improved fragilities. The enhanced analysis is likely to increase the calculated impact. It is also noteworthy that the impact assessed in this project represents the ‘direct’ losses. Consequential or ‘indirect’ losses include business disruption, impact on the workforce in distant locations, loss of market share on the international scene due to manufacturing and transportation disruption and loss, effect on tourism and erosion of the tax base. The indirect losses may be significantly higher than the direct losses, perhaps as high as twice or three times the values in the table above.

While this report investigates several hazard parameters and select inventory and fragility parameters there are still many areas were are not included. Many inventory categories are not updated and rely on HAZUS-MH default data. All regional buildings, including residential, commercial, industrial, essential facilities, transportation and utility facilities are not improved. In addition many default fragilities, with the exception of general building stock fragilities, are not improved. These categories include all transportation facilities and networks and all utility facilities and networks. Also regional demographics remain at the HAZUS-MH default level, which correspond to the most recent 2000 census. Fire, debris and social loss models are not updated or improved as well.

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1 Introduction

1.1 Definition of Loss Assessment

Loss assessment is the process by which the ramifications of a certain event are studied and consequential losses of various types are determined. One of the most common forms of loss assessment is the investigation of natural hazards and their impact on regional infrastructure. One of the most devastating natural hazards are earthquakes, the subject of the current report and project. In this context, seismic loss assessment is the determination of the impact of one or more earthquakes on the regional assets and societal systems of the area affect by the event(s).

Seismic loss assessment, or earthquake risk or impact assessment, requires addressing three primary and inter-related components; hazard, vulnerability and asset value (Scawthorn, 2006). Hazard parameters define the earthquake by specifying various quantities that characterize the severity of ground motion including ground acceleration, velocities, displacement or their spectral value counterpart. Asset value assessment requires the description of asset location, type and consequence of damage, which may be economical and/or functional. Inventory data sets catalogues all the buildings, bridges, roads, utility and lifeline facilities, dams, levees, power plants, population, etc. that lie within a region of interest. The sensitivity of the assets (inventory) to the hazard they are exposed to is characterized by fragility or vulnerability relationships. These fragilities assign a level of damage to each inventory item based on the hazard value experienced by that inventory item. Once a damage state is assigned to an asset, a loss value is associated with the inventory item. Subsequently all inventory losses are aggregated for a single regional loss or consequence value.

1.2 Necessity for Loss (Impact) Assessment

Loss assessment results provide a critical link between the occurrence of a hazard event, an earthquake in this case, and resources that are available in the aftermath of the hazard event. Linking pre- and post-hazard circumstances permits regional risk mitigation as well as response and recovery planning. Moreover, response and recovery planning may be viewed as an intricate combination of hazard-generate and response-generated demands (Harrald et al., 2007). Therefore, the relationship between response to the hazard even is intrinsically coupled with the impact of the event and cannot be decoupled or dealt with prior to impact assessment. Conducting seismic impact assessment identifies vulnerable infrastructure components, areas that are most susceptible to significant damage and loss as well as the lingering social impacts that may hinder the recovery of a region in the aftermath of an earthquake. By determining such quantities as the number of uninhabitable homes, functionality of hospitals and various other emergency response facilities and utility service interruptions, a region may be protected (Durham, 2006). Loss assessment is an absolute pre-requisite to mitigation measures; action taken before an earthquake to reduce its expected impacts.

Furthermore, loss assessment describes the state of a given region immediately after a hazard event. Understanding the damage, loss and needs of the studied region allows urban planners, government agencies and aid workers the opportunity to plan ahead (Harrald & Jefferson, 2006) for response and recovery. Reliable assessment results allow time and define objectives for groups involved in response and recovery to work together, develop plans and prepare so that services and aid workers are readily available for respond to the needs of affected communities. Therefore, loss assessment is an absolute pre-requisite to response and recovery planning.

To summarize, quantitative and reliable earthquake loss (impact) assessment is a necessary input into action for mitigating the consequences of a future earthquake (e.g. by retrofitting or other impact reduction measures) as well as articulating response and recovery plans to respond to the mitigated consequences.

1.3 Difficulties with Desktop Studies

It is common for seismic loss assessments to be conducted in the form of desktop studies using semi-empirical models which consider regional hazard, fragility and inventory to determine damage and loss. Several previous and even recent loss assessments focus on expert opinions, taking into account of the experience from urban planners, government aid agencies and local authorities. Recently loss assessments have shifted more towards computer-based methods that employ the results of sensor data, laboratory experimentation and field observations into account (Scawthorn, 2006, Elnashai, 2002 & 2004).

Seismic risk analyses produced with computer software often provide numerous default settings and values that permit a determination of loss, notwithstanding the regional applicability of these assumptions (FEMA-NIBS, *Technical Manual*, 2006). Completing a loss assessment without first considering the input data and analysis models, understanding their implications on damage and loss and relative accuracy of assessment results may lead to erroneous loss determinations. Since regional mitigation efforts and response and recovery plans are based on seismic loss assessments, providing unrealistic impact estimates has the potential to do totally undermine the validity of mitigation, response and recovery plans. Using non-representative data to prepare a region for a natural disaster may result in inadequate stockpiling of supplies, misplacing of the supplies or insufficiently retrofitting of structures, for example. In loss and impact assessment, imprudence is worse than lack of action.

Even apparent understanding of regional hazard and complete inventories is not enough to have an appreciation of the inherent uncertainty in seismic loss assessment. A seismically active region, such as the New Madrid Seismic Zone (NMSZ) may be assigned a specific probable earthquake intensity at a specific location, though there is a measurable probability that an earthquake with magnitude different to the predicted value occurs at an unexpected location. Moreover, the site conditions present in the region of interest are not available to a fine enough resolution to assign site-specific soil characteristics to every portion of the study region. Therefore, not only are the source and path characteristics uncertain, but also the surface motion.

Regional inventory provides another set of uncertainties. Any given inventory category may not represent every facility and asset within a study region as gathering data all structures is a time-consuming and capital-intensive process. Structure types for example may be incorrect or unassigned since it can be difficult to determine structure type during field surveys. For seismic impact assessment it is critical to ascertain the level of seismic design provisions present in each structure, which is often dependent on the year of construction and the building code employed during design. All of these design and construction parameters are difficult to obtain for every structure and thus are frequently assumed on an individual or geographic region bases. Lifelines, such as roads, bridges, utility networks, pose even more formidable problems due to the dispersion of the data sets, their proprietary nature and the age of some networks that predates regulations aimed at keeping tight inventory lists.

In summary, the sources of uncertainty in earthquake impact assessment are several and a full appreciation of their influence on the assessed consequences is required. Sources of uncertainty may be groups into:

Hazard:	Uncertainties on the fault mechanism, magnitude, location, fault dimension, travel path and surficial soil characteristics
Inventory:	Uncertainties about the asset counts, location and characteristics, such as physical parameters and condition.
Fragility:	Uncertainty about the response and damage state definition for the various types of assets that may or may not be designed to resist seismic actions.

There are other parameters that influence the outcome of the loss assessment exercise, such as unit values, repair costs, relationship between limit state of damage and loss of value, and others. It is therefore of extreme importance to assess the impact of earthquakes by varying the parameters influencing the assessment, within defensible limits, and providing Range of Impact, with an appreciation of uncertainty.

2 Seismic Loss Assessment Background

2.1 History of Loss Assessment

The early beginnings of earthquake causes and effects are in the 17th Century in the work of Robert Hooke and his lecture series, “Lectures and Discourses in Earthquakes and Subterranean Eruptions,” delivered to the Royal Society (Elnashai, 2002). His work and that of others, such as T. Young and R. Mallet provided the basis from which earthquake investigations and future seismic loss assessments sprung.

The work of three English engineers and their Japanese colleagues in the aftermath of the 1880, Yokohama earthquake prompted the formation of the Seismological Society of Japan. The efforts of the Society included the study of earthquakes and the development of seismic design codes to reduce damage. The first form of seismic design provisions, however; were developed by a group of Italian engineers in the wake of the devastating Messina, Italy, earthquake of 1908 (Scawthorn, 2006). These provisions specify the assignment of a portion of the weight of the structure as a horizontal earthquake force. Recommendations included those of the Politecnic of Turin’s Professor M. Panetti who suggested that 1/12th the weight be applied to the first floor while second and third floors receive 1/8th of the weight (Elnashai, 2006). Methods such as these are referred to as equivalent static approaches and are still used today in all seismic design codes.

Various other historical earthquakes played critical roles in the development of seismic risk knowledge including; the 1906 San Francisco earthquake, 1923 Tokyo (Kanto) earthquake, 1925 Santa Barbara earthquake and the 1933 Long Beach earthquake. The historic San Francisco earthquake exposed investigators to the vast damage caused by fires following an earthquake. Sizeable portions of the San Francisco harbor area burned as broken water lines inhibited the amount and pressure of water delivered to burning areas. The Santa Barbara earthquake sparked the interest of J.R. Freeman, an insurance professional, curious about the impact of earthquakes and their relation to insurance compensation (Di Sarno et al., 2006, Scawthorn, 2006). With the insurance industry now apprised to the affects of earthquakes seismically active areas became subject to modified rates resulting from increased risk levels. Lastly, the Long Beach earthquake prompted California to adopt the Field and Riley Acts which mandate the use of seismic design for schools and other critical buildings (Scawthorn, 2006). This is the beginning of essential facilities definition, as critical facilities are identified and their post-earthquake operation protected.

More recent earthquakes have tested roughly two centuries of earthquake knowledge, research and design provisions. The 1989 Loma Prieta earthquake (Jones et al., 1995), 1994 Northridge earthquake (Rodgers et al., 2006) and 1995 Kobe earthquake (Kim et al., 2002) served as reminders of how drastic urban damage can be. Within the same time frame various companies and organizations developed numerous seismic loss assessment software packages including; *EQEHAZARD* and *EQECAT* developed by EQE, *EPEDAT*, *Shakemaps*, *AIR, EXTREMUM* and the derivative program *QUAKELOSS*, and *HAZUS-MH* developed by the Federal Emergency Management Agency (FEMA). Risk Management Solutions, RMS, developed its own version of loss assessment software 'RiskLink' for various hazards including earthquakes. HAZUS-MH is the software package of choice in the research presented hereafter and is discussed at length in subsequent sections. In comparison to various other scientific fields, earthquake analysis and seismic loss assessment are relatively new, though the strides made to advance this field in its short 150-200 year lifespan have provided substantial scientific and economic contributions.

2.2 Previous Seismic Loss Assessment Studies

HAZUS-MH has been employed by various government agencies, private organizations, research groups and professional associations to undertake seismic loss assessment studies in various regions of the USA. The Washington Military Department Emergency Management Division, in conjunction with the Earthquake Engineering Research Institute (EERI), conducted a loss assessment of a magnitude 6.7 earthquake on the Seattle Fault in 2005. This scenario predicted roughly $35 billion in losses (EERI & Washington Military Dept., 2005).

The Hayward Fault in the San Francisco Bay Area was the focus of a seismic loss assessment in 1996. Damage to local infrastructure and its impact on residents placed regional loss greater than 1% of the gross product of the area, or $1.8 billion. In this report, however; upper limits to regional losses are set at as much as $4 billion, which may in fact be more realistic than the $1.8 billion expected initially (EERI, 1996), however.

HAZUS-MH was also utilized for a Level III analysis for the state of South Carolina. This analysis consisted for four separate hazard scenarios, though the earthquake of greatest magnitude, M 7.3, was meant to replicate the Charleston, South Carolina, earthquake of 1886. The Level III analysis completed is the most improved analysis available in HAZUS-MH and incorporates advanced data and models in various aspects of regional loss modeling. The above are just examples of loss assessments conducted in the USA, though numerous other national and international studies exist.

Regional hazard for the above study was developed through an external stochastic model that combined point-source and finite-fault components. Once the required input ground motion parameters were determined these values were modified with amplification factors to account for soil effects. A significant feature in this study is the use of a 2x2 km grid for hazard definition (Wong et al., 2005). HAZUS-MH default setting defined ground motion on a census tract basis. Since higher resolution of the ground motion was required, a finer grid was implemented. Detailed studies were also performed within the context of the South Carolina loss assessment to evaluate surficial, deep soil deposits and ground water levels for more accurate mapping of soil condition and liquefaction susceptibility. Additionally, land-sliding susceptibility was evaluated state-wide and included in the loss model.

Building inventories were updated using the 2x2 km grid as well. Seismic design levels and quality characteristics were improved. Essential facilities inventories were also improved. Transportation and utility lifeline inventories were modified with the most up-to-date information available at the time of the study.

Numerous scenarios were analyzed and various sensitivity studies completed. Regional losses for a repeat of the 1886, Charleston earthquake were determined to be $20 billion with over $14 billion attributed to buildings damage alone (Wong et al., 2005).

This loss assessment also predicted 44,000 injuries and as many as 900 deaths. Schools and fire stations were also highlighted as structures particularly susceptible to significant damage. Wide-spread failure of the potable water distribution system was also predicted, depriving roughly 80% of urban households of potable water. Numerous other damage and loss parameters are highlighted in the study though they are not discussed here. This study serves as a guideline for others interested in completing seismic loss assessment studies with improved model parameters.

2.3 Multi-Disciplinary Approach to Seismic Impact Assessment

2.3.1 Participating Disciplines

Though seismic loss assessment began as a study in earthquakes and seismic design codes, the field has grown to include disciplines stretching from science and engineering to social sciences and urban planning. This multi-disciplinary approach affords loss assessment teams the expertise required in all stages of regional loss modeling including hazard definition, infrastructure response, economic loss modeling and social impact.

Loss assessments require the definition of a hazard event which employs the talents and expertise of geophysicists and engineering seismologists. Ground motion parameters based on fault locations and ruptures must be determined. Additionally, site characterization values are required for more accurate loss assessments, and are provided by geotechnical engineers. The determination of soil types and liquefaction susceptibilities are important features that are also provided by geotechnical engineers.

The determination of structural and non-structural fragility functions for buildings, bridges and numerous other infrastructure components is the task of engineers, primarily structural engineers. These fragilities include the seismic response measure at which various damage states are reached. These damage states may signify such levels as immediate building occupancy, life safety and collapse prevention. Structural fragilities are often defined by peak ground acceleration (PGA), spectral acceleration or spectral displacement depending on the component.

The development of inventory gathering technologies and procedures is completed by urban planners and GIS experts. Without the proper regional inventory loss assessments are of little or no use, thus the cataloguing of accurate inventory items is critical to a reliable loss assessment. The development of economic loss models also falls to social scientists. Regional losses can not be determined without appropriate depictions of the regional economy. Another significant contribution from social science is the modeling of impact on societal systems such as housing, education and healthcare.

Though not strictly applicable to loss assessment, response and recovery planners are one of the primary users of the impact studies. The development of plans for post-disaster aid is the responsibility of emergency managers and community coordinators. The creation and location of stockpiles of medical supplies, food, water, emergency shelter, temporary housing, etc. are all organized by response and recovery planners, in conjunction with various government and private aid agencies, and is based on the expected impact provided in a seismic loss assessment studies. This diverse group of scientists, economists, social scientists, city planners and response and recovery workers function as one cohesive unit to develop comprehensive seismic risk management.

2.3.2 Challenges in Seismic Loss Assessment

With all the benefits provided by seismic loss assessment these studies are still complex and challenging to undertake. The most accurate loss assessment requires the most complete inventory data and hazard information as well as accurate infrastructure component and system fragilities, and their interaction, alongside realistic economic and social consequences models. The collection of this data is a time-consuming and uncertain endeavor, requiring the cooperation of numerous individuals and agencies. In addition, some data does not exist or does not exist in a usable form (e.g. paper-based) and there are only minimal funding opportunities available to develop comprehensive inventories.

Regional demographics are required to determine displaced populations, shelter requirements and various other social consequences. Population statistics must include the overall populations as well as population breakdowns by age, gender, occupation, income, ethnicity, school age children, and the numbers of people working, commuting and at-home are various times of the day. This data is not readily available for all regions, nor is it updated in all cases. The US national census is conducted every ten year and provides the required demographic information, though mid-term this data is out-of-date.

Hazard characterization is dependent upon site characteristics amongst other seismological, geological and geotechnical parameters. Obtaining reliable site classification requires rather extensive field testing. These field studies are time-consuming and costly for large regions, and thus are not often commissioned. Liquefaction and land-sliding susceptibility data is acquired in the same manner indicating that the gathering of regional hazard data is a formidable challenge in its own right. If highly refined site information exists it is often for region of limited geographical extent, such as a city or a county. Furthermore, the method by which ground motion is defined is critical to the overall hazard definition process. Options include point-source and finite-fault models, and the method chosen will impact the evaluation of ground motion at various locations. Acquiring reliable data and choosing an appropriate hazard model are two of the primary challenges faced when defining regional hazard.

Region inventory may also reduce the accuracy of loss assessments. Complete data sets detailing building, transportation network, utility network, hazardous materials facilities and high-potential loss facilities is required and often difficult to obtain. The most accurate inventory incorporate all of these data items with point-wise data for individual facilities, though this level of inventory data refinement is also time-consuming and costly to obtain. Buildings alone require individual locations, structure type, seismic design level, number of stories, occupancy and use parameters, as well as contents information. When complete inventories for bridges, highways, railways, buses, ports, airports, potable and waste water systems, natural gas and oil systems and electric power and communication systems are added the data collection task, the enormity of the challenge in conducting reliable risk assessment becomes evident.

The probabilistic performance of infrastructure components during earthquakes is defined by fragility functions. These fragility functions, or curves, are required for all inventory components, not just buildings and bridges where fragility functions are rather abundant. Other lifeline components including pipelines and utility distribution networks, roads and railway tracks, dams and levees, and several others are also needed. Several of the required fragilities do not exist, and the loss modeling effort has to resort to empirical and expert-opinion-based approaches, thus reducing the reliability of the assessment outcome.

Finally, regionally appropriate social and economic consequence models are required to determine accurate impacts. These models, which depend on measures of social vulnerability and regional macro-economics, may be difficult to determine depending on the area under investigation. Regional social and economic impact modeling as well as hazard, inventory and fragilities all contribute to the challenges presented to those attempting to conduct detailed and reliable seismic loss assessments.

3 HAZUS Overview and Methodology

3.1 Levels of Analysis

All of the loss assessment analyses completed in this research project are conducted with HAZUS-MH MR2 (2006), a software package developed and distributed by FEMA and the National Institute of Building Sciences (NIBS). As previously discussed, HAZUS-MH uses three primary components to estimate damage and loss values; hazard, inventory and fragility. The developers of HAZUS-MH have specified three levels of assessment based on the refinement and improvement of analysis components (See Figure 1). The most basic of these is a Level I analysis, which relies on HAZUS-MH default values heavily. In this case hazard must be defined by the user, whether it is an arbitrary point-source epicenter, historical event (for Western U.S only) or via user-supplied hazard maps. Additionally, site characteristics are assigned a standard Site Class ‘D’ and adhere to (NEHRP) guidelines for site class response. Inventory and fragility components, however; are taken as default analysis components within the software itself. Provided inventory and fragilities cover major infrastructure divisions such as regional population demographics, essential facilities, transportation networks and facilities, utilities facilities, general building stock, hazardous materials facilities and high potential loss facilities. Analyses at this level are based on building square footage and value, population characteristics, costs of building repair and basic economic data (FEMA-NIBS *User’s Manual*, 2006). Developers stipulate, however; that assessments employing a Level I analysis have a large margin for uncertainty and thus are best-suited as a starting point from which improved analyses stem. Separate analyses with updated hazard, inventory and fragility parameters are then compared to the Level I analysis to determine the impact of individual components on regional damage and losses.

More accurate loss assessments are accomplished in HAZUS-MH via the addition of hazard, inventory and fragility data for a given study region. A Level II analysis incorporates site-specific soil characteristics through the use of maps specifying site class, liquefaction susceptibility and landslide potential. All of these factors impact ground shaking levels and the attenuation of these motions at various periods and distances from a given epicenter. Supplementing the default data in HAZUS-MH with this site information alone provides a more accurate estimate of ground shaking and liquefaction behavior which ultimately improves damage and loss values throughout a study region (Bausch, "HAZUS Applications…", 2006).

Inventory improvements also play an important role in Level II analyses. Local estimates of building square footages by building type, detailing inventories of essential facilities, adding utility networks, updating data for high potential loss facilities and hazardous material facilities, updating transportation facility and network information are all classified at Level II improvements. Improving fragilities for various inventory components, particularly buildings, bridges and lifeline networks, are also classified as Level II improvements. In addition, various updates to economic models for transportation and utility lifelines and induced damage models through the development of inundation maps and taking into account local factors for indirect economic loss models. Completion of a Level II HAZUS-MH analysis requires considerable time and effort with regard to data collection and preparation, thus all possible data upgrades are not completed. Component improvement is often selected based on the availability of information and time constraints placed on a project team.

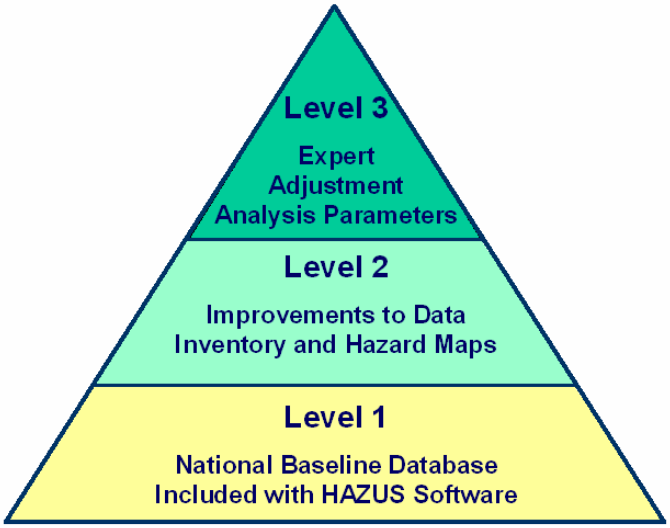


Figure 1: Levels of Analysis in HAZUS-MH

A Level III analysis is the most regionally accurate form of loss assessment in HAZUS-MH. Once inventory, hazard and fragility components are improved in Level II the only remaining improvement suggested by program creators is to incorporate expert opinion (FEMA-NIBS *Technical Manual*, 2006). The Technical Draft of the HAZUS-MH Earthquake Manual cites engineering and economic study results completed outside HAZUS-MH as an "Advanced Data and Models Analysis," for Level III. The use of outside technical expertise in these fields is recommended as well as close cooperation of local utilities and special facility owners, in an effort to develop the best damage and loss models. This is by far the most complicated and time consuming form of loss assessment in HAZUS-MH.

3.2 Hazard

3.2.1 Definition of Regional Ground Motion

Earthquake hazards take two forms within HAZUS-MH; deterministic and probabilistic events. The latter is based on ground shaking demand as characterized by 2002 United States Geological Survey spectral contour maps for rock sites, or site class 'B' (FEMA-NIBS, *Tech. Manual*, 2006). In addition the user may provide the required probabilistic maps developed via alternate methods. Eight probabilistic analysis options are provided within the program and range from 39% probability of exceedance in 50 years to 2% probability of exceedance in 50 years. These probabilities of exceedance correspond to return periods of 100 years to 2,500 years, respectively. A magnitude must be specified for this form of analysis, or probabilistic maps may be provided by the user and imported into HAZUS-MH. In this report, due to the nature of the problem under investigation and the objectives of the study, a deterministic scenario is used, comprising the largest magnitude that is based on the capability of the known faults in the NMSZ.

Deterministic events are defined by the same ground motion parameters as probabilistic events. Peak ground acceleration, peak ground velocity, and spectral accelerations at 0.3 second period and 1.0 second period are calculated for a single seismic event. At the most basic level ground motion parameters are not affected by soil characteristics. These four ground motion parameters are the only input values required to determine damage states within HAZUS-MH since all other ground motion parameters (e.g. spectral velocities and displacements) are based on those four values.

There are numerous methods to define a deterministic event within HAZUS-MH, the first of which being the selection of a historical event. HAZUS-MH houses a database of over 8,000 past earthquake ground motion records which can be assigned to analyses.

This type of analysis provides relevant location, depth and magnitude values (FEMA-NIBS, *Technical Manual*, 2006) for a given event, though this option is available for the western U.S. primarily. Additionally, certain types of fault rupture events are reserved for the western U.S. including strike-slip, reverse and normal fault rupture. Furthermore, the combination of attenuation relationships associated with the western U.S. tend to produce weaker ground shaking values than the combined CEUS attenuation relations for the same moment magnitude and source-to-site distance (FEMA-NIBS, *Technical Manual*, 2006).

Seismic events can be defined with the 'Arbitrary Event' option in HAZUS-MH, though certain event characteristics are limited by geographic region. This form of hazard assignment requires latitude and longitude values to specify and epicenter as well as a magnitude value to quantify earthquake intensity. Earthquake rupture depth can also be specified, though the default value of 10 km is sufficient for the majority of the New Madrid Fault. Rupture depths less than 10 km (approximately 5-8 km) are suggested for the northern portion of the NM Fault, though 10 km is applicable to the central and southwest thrust, so the default depth of 10 km is used for each fault extension for simplicity of analysis.

Analyses using the 'arbitrary event' hazard definition option are computed based on one of two groups of attenuations; the CEUS Event and CEUS Characteristic Event alternatives. The CEUS Event incorporates four attenuation functions developed by Frankel et al. (1996), Toro et al. (1997), Atkinson and Boore (1995) and Campbell (2002) weighted in the following manner:

Table 1: CEUS Event Attenuation Functions and Weight Factors

Participating Attenuation Functions	Weighting Factor
Atkinson and Boore (1995)	0.286
Toro, Abrahamson and Schneider (1997)	0.286
Frankel et al. (1996)	0.286
Campbell (2003)	0.142

The CEUS Characteristic Event includes an additional attenuation relation developed by Somerville et al. (2002), with attenuation function weighting factors adjusted as shown below:

Table 2: CEUS Characteristic Event Attenuation Functions and Weight Factors

Participating Attenuation Functions	Weighting Factor
Atkinson and Boore (1995)	0.250
Toro, Abrahamson and Schneider (1997)	0.250
Frankel, Mueller, Barnhard, Perkins et al. (1996)	0.250
Campbell (2003)	0.125
Somerville et al. (2002)	0.125

The attenuations developed by Frankel et al. are available in tabular format only and include values for PGA, spectral acceleration at 0.2 seconds and spectral acceleration at 1.0 seconds based on magnitudes from 4.4 to 8.2 and hypocentral distances, r_{hypo}, of 10 to 1000km. All other attenuation functions consist of logarithmically decreasing functions modified with constants as detailed below:

Atkinson and Boore:

$$\log(Y) = C_1 + C_2(M-6) + C_3(M-6)^2 - \log(R) - C_4 R$$

where: Y = Response parameter (PGA, PGV, S_a);
$C_1 - C_4$ = Regression Coefficients;
M = Moment Magnitude;
R = Hypocentral distance (km)

Table 3: Atkinson and Boore Attenuation Function Constants

Period	C_1	C_2	C_3	C_4
PGA	3.79	0.298	-0.0536	0.00135
0.2	3.75	0.418	-0.0644	0.000457
1.0	2.77	0.620	-0.0409	0.0000

Toro, Abrahamson and Schneider:

$$\ln(Y) = C_1 + C_2(M-6) + C_3(M-6)^2 - C_4 \ln(R_M) - (C_5 - C_4)\max\left[\ln\left(\frac{R_M}{100}\right), 0\right] - C_6 R_M$$

$$R_M = \sqrt{{R_{jb}}^2 + {C_7}^2}$$

where: Y = Response parameter;
$C_1 - C_7$ = Modeling constants;
M = Moment magnitude;
R_{jb} = Epicentral distance (km)

Table 4: Toro, Abrahamson and Schneider Attenuation Function Constants

Period	C_1	C_2	C_3	C_4	C_5	C_6	C_7
PGA	2.20	0.81	0.00	1.27	1.16	0.0021	9.3
0.2	1.73	0.84	0.00	0.98	0.66	0.0042	7.5
1.0	0.09	1.42	-0.20	0.90	.49	0.0023	6.8

Campbell:

$$\ln(Y) = C_1 + f_1(M) + f_2(M, r_{rup}) + f_3(r)$$

where: $f_1(M) = C_2M + C_3(8.5\text{-}M)_2$;

$f_2(M,r_{rup}) = C_4\ln(R) + (C_5 - C_6M)r_{rup}$;

$R = \sqrt{{r_{rup}}^2 + \left[C_7 e^{(C_8 M)}\right]^2}$;

$f_3(r) = 0$ for $r_{rup} \le r_1$;

$C_7(\ln(r_{rup}) - \ln(r_1))$ for $r_1 < r_{rup} \le r_2$;

$C_7(\ln(r_{rup}) - \ln(r_1)) + C_8(\ln(r_{rup}) - \ln(r_2))$ for $r_{rup} > r_2$;

Y = Mean of response parameter;

$C_1 - C_8$: Regression coefficients;

M = Moment magnitude;

r_{rup} = hypocentral distance (km);

r_1 = 70 km;

r_2 = 130 km;

Table 5: Campbell Attenuation Function Constants

Period	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
PGA	0.0305	0.633	-0.0427	-1.591	-0.00428	0.000483	0.683	0.416
0.2	-0.4328	0.617	-0.0586	-1.320	-0.00460	0.000337	0.399	0.493
1.0	-0.6104	0.451	-0.2090	-1.158	-0.00255	0.000141	0.299	0.503

The CEUS Characteristic Event includes the attenuation developed by Somerville, Collins and Abrahamson et al. according to the following functions and constants:

Somerville et al.:

For a hard rock site:

For $r < r_1$ -

$$\ln(S_a(g)) = c_1 + c_2(M - m_1) + c_3\ln(R) + c_4(M - m_1)\ln(R) + c_5 r + c_7(8.5 - M)^2$$

For $r \ge r_1$ –

$$\ln(S_a(g)) = c_1 + c_2(M - m_1) + c_3\ln(R1) + c_4(M - m_1)\ln(R) + c_5 r + c_6(\ln(R) - \ln(R_1)) + c_7(8.5 - M)^2$$

where: $S_a(g)$ = Spectral acceleration (g);

$m_1 = 6.4$;

$r_1 = 50$ km;

$h = 6$ km;

$R = (r^2 + h^2)^{(1/2)}$;

$R_1 = \sqrt{r_1^{\,2} + h^2}$;

M = Moment magnitude;

R = epicentral distance (km)

Table 6: Somerville, Collins, Abrahamson et al. Attenuation Function Constants

Period	C1	C2	C3	C4	C5	C6	C7
Rift Zone							
0.2	0.793	0.805	-0.679	0.0861	-0.00498	-0.477	0.0000
1.0	-0.307	0.805	-0.696	0.0861	-0.00362	-0.755	-0.1020

The arbitrary event attenuation functions described above include no provision for the calculation of peak ground velocity (PGV). HAZUS-MH employs the long period (1.0 second) spectral acceleration value from which PGV is inferred, in units of inches per second. The factor of 1.65 in the denominator is a weighting factor used to amplify PGV from spectral acceleration and is based on the work of Newmark and Hall (1982) (FEMA-NIBS, *Technical Manual*, 2006).

$$PGV = \frac{\left[\left(\frac{386.4}{2\pi}\right) S_{A1}\right]}{1.65}$$

Further modifications to ground shaking include the inference of 0.3-second period spectral acceleration from 0.2-second period spectral acceleration. For the CEUS this adjustment is accomplished via the division of the typical 0.2-second period spectral value by a factor of 1.4.

The attenuation relationships discussed previously incorporate epicentral distances based on Figure 2. While variable for dip angle and fault width may not apply to the CEUS Event or CEUS Characteristic Event equations all other distances are used to determine seismic response parameters at each census tract. Individual census tracts are assigned PGA, PGV and S_a values at the tract's centroid, meaning ground motion is attenuated to the centroid then assigned to the entire census tract for use in the determination of damage states of various infrastructure components. The same principle

Central and Eastern US Attenuation Functions	Distance
Atkinson and Boore (1995)	r_{hypo}
Toro, Abrahamson and Schneider (1997)	r_{jb}
Frankel, Mueller, Barnhard, Perkins, Leyendecker, Dickman, Hooper (1996)	r_{hypo}
Campbell (2002)	r_{rup}
Sommerville, Collins, Abrahamson, Braves, and Saikia (2002)	r_{jb}

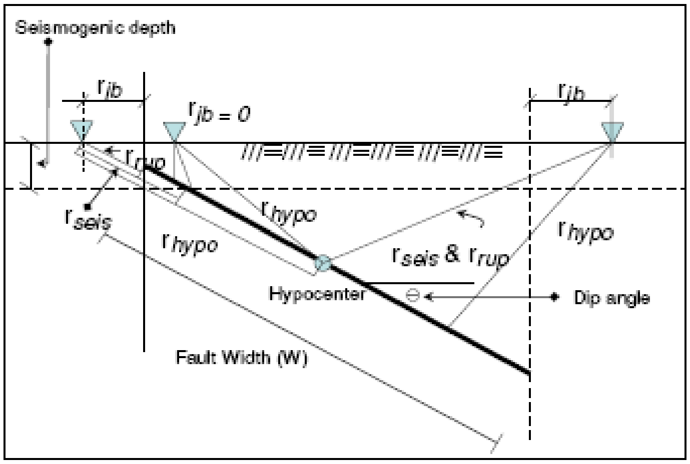


Figure 2: Source-to-Site Distances

of centroid assignment applies to site class, liquefaction susceptibility, landslide susceptibility and water depth site characterization parameters. Instead of averaging the site characteristic over the entire census tract and applying the averaged value to adjust ground motion and infrastructure fragilities, HAZUS-MH recognizes the site characterization parameter at the centroid only and uses that value to modify ground motion, fragilities and economic models, despite the potential presence of variation of any given site characterization parameter within a census tract. The study region used in this research is discussed in detail in subsequent sections, however; the map of census tract centroid locations for the study region employed in this research is illustrated in Figure 3.

Despite the use of a regionally appropriate combination of attenuation relations HAZUS-MH presents a critical attenuation deficiency. All ground motion values are truncated at a source-to-site distance of 200 km. Within the first 200km of the epicenter ground motions are calculated based on the specified equations. At distances greater than 200 km, however; all ground motion values are assigned zero values. This is an arbitrary cut-off distance determined by HAZUS-MH developers and assumed to provide adequate regional coverage for ground motion attenuation. Large regions experience extensive assignment of null ground motion values which is not representative of actual ground motion propagation, which is the case in this research.

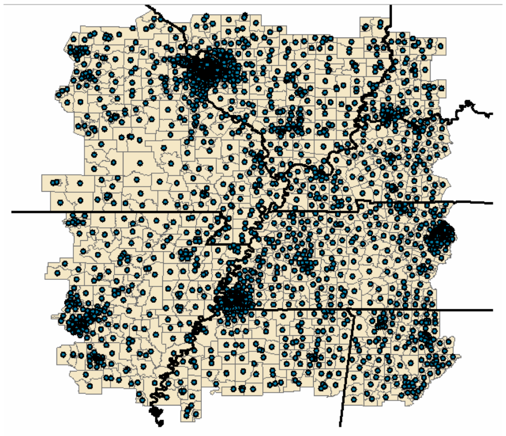


Figure 3: Census Tract Centroids

Such serious program limitations necessitate the use of the ‘User-Supplied Hazard Maps’ feature. It is possible to apply the HAZUS-MH combined attenuations outside of the program for the development of the four required ground motion maps and bypass the 200 km cut-off limitation. Yet another option is to develop ground motion maps based on the USGS procedure for ground motion assignment resulting from USGS-determined probable earthquake locations and magnitudes. The former alternative is chosen and applied to this research through the incorporation of the CEUS Event, while the latter is incorporated in a baseline study completed over a similar region by the Federal Emergency Management Agency (FEMA). Both methods are discussed in greater detail in subsequent sections.

3.2.2 Regional Hazard Modification

HAZUS-MH allows for the inclusion of various site parameters including site class, liquefaction susceptibility, landslide potential and water depth as mentioned earlier. Computations of local site affects are carried out using the National Earthquake Hazard Reduction Program (NEHRP) Provisions for ground motion characterization. These provisions specify six site classes, ranging from ‘A’ to ‘F’ to determine the composition of local soils. Table 7 illustrates the properties required by NEHRP for site class assignment:

Table 7: NEHRP Site Classes and Shear Wave Velocities (FEMA 450)

Site Class	Description	Shear Wave Velocity (m/sec.)	
		Minimum	Maximum
A	Hard Rock	1500	--
B	Rock	760	1500
C	Very Dense Soil & Soft Rock	360	760
D	Stiff Soils	180	360
E	Soft Soils	--	180
F	Soils Requiring Specific Evaluation	--	--

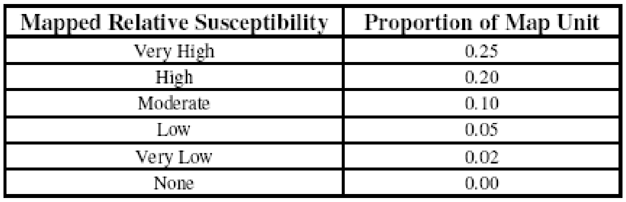
NEHRP factors are provided for spectral acceleration values only, and no provisions are specified to account for PGA and PGV. A 'base' or reference site class is required to determine amplification and reduction factors for the remaining soil types. Site class 'B' is chosen as the reference site, from which all other classes are modified. Modification factors for each site class are shown in Table 8. These factors indicate a reduction in spectral acceleration of all periods for all site classified as hard rock. As sites become less rock-like and include more soft soil amplification factors increase, particularly for long period spectral acceleration. Note that for site class 'D' long period spectral accelerations of less that 0.2*g* are at least double that of site class 'B' values. Site class 'E' amplifies ground motions even further by increasing long period spectral acceleration up to 3.5 times that of reference site class. Higher shaking values at longer period are amplified less, though still experiencing significant amplification, such as at 0.5*g*. Short period spectral accelerations, however; are reduced for intense shaking values (i.e. $S_{AS} > 1.0g$) while lesser intensities are amplified up to 2.5 times that of shaking values of site class 'B'.

Table 8: NEHRP Soil Amplification Factors (FEMA 450)

Site Class B Spectral Acceleration	Site Class				
	A	B	C	D	E
Short Period, S_{AS} (g)	Short-Period Amplification Factor, F_A				
≤ 0.25	0.8	1.0	1.2	1.6	2.5
0.50	0.8	1.0	1.2	1.4	1.7
0.75	0.8	1.0	1.1	1.2	1.2
1.0	0.8	1.0	1.0	1.1	0.9
≥ 1.25	0.8	1.0	1.0	1.0	0.8
1-Second Period, S_{A1} (g)	1.0-Second Period Amplification Factor, F_V				
≤ 0.1	0.8	1.0	1.7	2.4	3.5
0.2	0.8	1.0	1.6	2.0	3.2
0.3	0.8	1.0	1.5	1.8	2.8
0.4	0.8	1.0	1.4	1.6	2.4
≥ 0.5	0.8	1.0	1.3	1.5	2.0

Liquefaction is another factor that is critical to the accurate determination of hazard in a given study region. Susceptibility to liquefaction is dictated by the type of soil, grain size distribution and relative density of local soils and relates the interaction of soil to ground motion, in particular the amplitude and duration of shaking. Permanent ground deformation is a direct result of liquefaction probability and thus the incorporation of liquefaction susceptibilities is vital to the calculation of lifeline damage, especially pipeline network damage. HAZUS-MH provides a default liquefaction mapping scheme for a generic study region as a function of percentage of region area, as shown in Table 9. Users may also opt to specify liquefaction susceptibilities with a map attached to the

Table 9: Proportion of Map Unit Susceptible to Liquefaction - HAZUS-MH Default



Mapped Relative Susceptibility	Proportion of Map Unit
Very High	0.25
High	0.20
Moderate	0.10
Low	0.05
Very Low	0.02
None	0.00

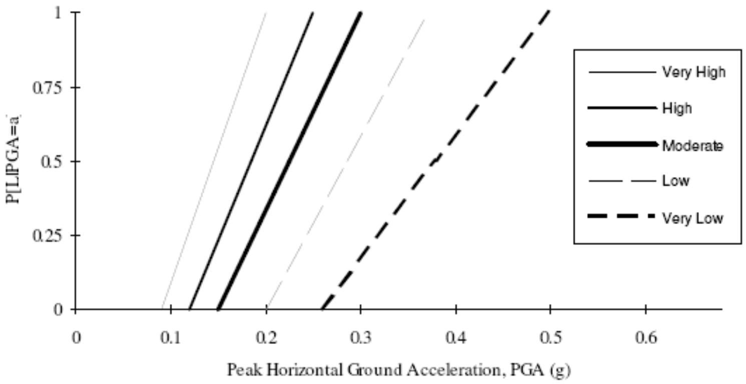


Figure 4: Conditional Probability Relationships for Liquefaction Susceptibility (FEMA-NIBS, *Technical Manual*, 2006)

study region. The map attachment process updates all inventory fragilities and loss models to reflect the liquefiable nature of regional soils. For both default and user-supplied liquefaction susceptibility values, however; only six broad categories of susceptibility exist. These categories are shown in Table 9 and the related probability of liquefaction relationships are illustrated in Figure 4. These relationships are calculated from the liquefaction probability equation which specifies the likelihood of liquefaction for a given liquefaction susceptibility, moment magnitude (via PGA) and groundwater depth.

$$P\left[Liquefaction_{SC}\right] = \frac{P\left[Liquefaction_{SC} \middle| PGA = a\right]}{K_M K_W} * P_{ml}$$

where; K_M = Moment magnitude correction factor for magnitudes other than M=7.5;
K_W = Ground Water Correction Factor for depths other than five feet;
P_{ml} = Proportion of Map Unit Susceptible to Liquefaction;
P[Liquefaction$_{SC}$ | PGA=a] = Conditional Liquefaction Probability for a Given Susceptibility Category at a Specified Level of PGA

Correction factors are then defined according to the following equations:

$$K_M = 0.0027M^3 - 0.0267M^2 - 0.2055M + 2.9188 \ ;$$
$$K_W = 0.022d_W + 0.93$$

where M = Moment magnitude of seismic event;
d_W = Depth to groundwater in feet

Not only do high probabilities of liquefaction increase the probabilities of extensive damage, they also contribute to permanent ground deformations by way of lateral spreading and ground settlement. Lateral spreading calculations are based on Youd and Perkins' Liquefaction Severity Index combined with Sadigh et al.'s attenuation relationship. This requires the normalization of PGA to a liquefaction probability of zero. Permanent ground deformation due to lateral spreading is determined as follows:

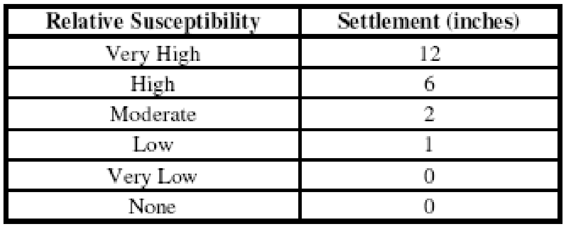
$$E\left[PGD_{SC}\right] = K_\Delta * E\left[PGD \middle| \left(PGA / PL_{SC}\right) = a\right]$$

where: E[PGD | (PGA/PL$_{SC}$)=a] = Expected permanent ground displacement for a given susceptibility category to a normalized ground shaking level (PGA/PGA)t);
PGA(t) = Threshold ground shaking required to induce liquefaction;
K_Δ = displacement correction factor;
M = Moment Magnitude

$$K_{\Delta} = 0.0086M^{3} - 0.0914M^{2} + 0.4698M - 0.9835$$

Ground settlement is the final displacement field related to liquefaction susceptibility. HAZUS-MH assumes the susceptibility of a given area is directly related to ground settlement experienced. Work done by Tokimatsu and Seed in 1987 is cited by FEMA and NIBS to show that higher susceptibility soils typically have greater deposit thickness of potentially liquefiable soils. In addition, strong correlations between volumetric strain and soil relative density are considered proof of the validity of the assumption that liquefaction susceptibility relates directly to ground settlement. Settlement values are classified by susceptibility category as shown in Table 10.

Table 10: Ground Settlement Amplitude by Liquefaction Susceptibility Category



Relative Susceptibility	Settlement (inches)
Very High	12
High	6
Moderate	2
Low	1
Very Low	0
None	0

Additional criteria employed to determine hazard include landslide susceptibility and ground water depth. The latter is assumed to have a five-foot default depth in HAZUS-MH. While the user may supply a ground water depth map this form of information is not incorporated herein, deferring to the default depth for all analyses. Landslide susceptibility does not include a default value, or set of values, in HAZUS-MH. All landslide information must be supplied by the user and is related to the surficial geologic makeup, slope angle and acceleration from a seismic event present in region under investigation. Landslide susceptibility is excluded from this research, though is a hazard component recommended for future work.

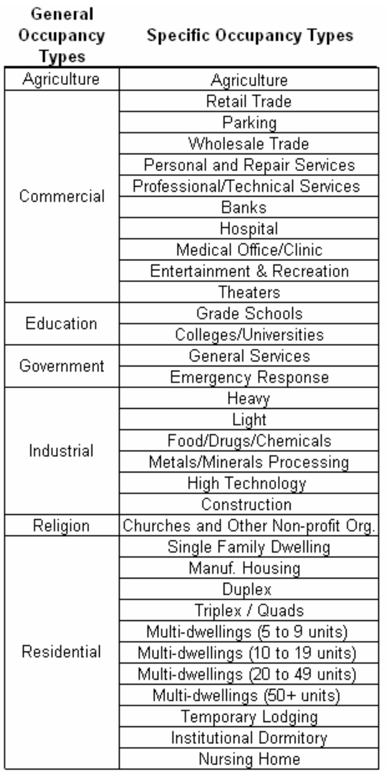
3.3 Inventory

HAZUS-MH provides extensive inventory databases for numerous infrastructure components and lifeline networks which are utilized in regional analyses. Inventory items are divided into several major categories including; demographic data, general building stock, essential facilities, high potential loss facilities, hazardous materials facilities, transportation lifelines and utility lifelines. All but one of these data groups refers to the built environment, while demographic data provides extensive population statistics nationwide. Various categories detailed within the demographic data provided in HAZUS-MH include; age, gender, race, ethnicity, income, hotel population, working population, marriages, numbers of residents living in particular types of dwelling (single family, apartment, etc.), construction years of residential buildings, property values and school population. While this database is extensive and provides sufficient information for characterization of regional residents, their economic, age and racial diversity, the information is out of date. A national census occurs every ten years in the U.S. with the latest census occurring in 2000. All demographic data supplied in HAZUS-MH is taken from this 2000 census and may not be truly representative of 2006 demographics.

The remaining inventory items consist of data on the built environment. There are two forms of database organization; point-wise data and census tract level data. Point-wise data specifies a specific coordinate location of a particular inventory item such as a building, bridge or length of road. Inventory sets employing this type of data specificity include; essential facilities, transportation facilities as well as roads, runways, etc., utility facilities, hazardous materials facilities and high potential loss facilities. The general building, however, is defined on a per census tract basis. This broad category is comprised of all buildings within a census tract. Providing a comprehensive, national building inventory would require excessive amounts of time to research and compile data, and thus general building stock inventory is based on assessment records which are used to estimate the number, square footage, occupancy type and dollar exposure of all buildings within a given census tract.

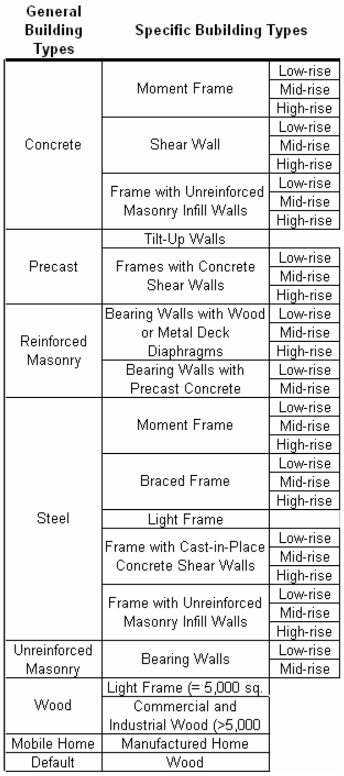
The general building stock employs two types of mapping schemes for occupancy and building type; general and specific schemes. Occupancy types refer to the general or specific use or function of a building, while building type refers to the material, height and structure types of a building. General and specific classifications for the general building stock are detailed in Table 11and Table 12, respectively. All 36 model building types found under the specific building types are based on model building types found in FEMA 178: *NEHRP Handbook for the Seismic Evaluation of Existing Buildings* (FEMA-NIBS, *Technical Manual*, 2006).

Table 11: HAZUS-MH Occupancy Types



General Occupancy Types	Specific Occupancy Types
Agriculture	Agriculture
Commercial	Retail Trade
	Parking
	Wholesale Trade
	Personal and Repair Services
	Professional/Technical Services
	Banks
	Hospital
	Medical Office/Clinic
	Entertainment & Recreation
	Theaters
Education	Grade Schools
	Colleges/Universities
Government	General Services
	Emergency Response
Industrial	Heavy
	Light
	Food/Drugs/Chemicals
	Metals/Minerals Processing
	High Technology
	Construction
Religion	Churches and Other Non-profit Org.
Residential	Single Family Dwelling
	Manuf. Housing
	Duplex
	Triplex / Quads
	Multi-dwellings (5 to 9 units)
	Multi-dwellings (10 to 19 units)
	Multi-dwellings (20 to 49 units)
	Multi-dwellings (50+ units)
	Temporary Lodging
	Institutional Dormitory
	Nursing Home

Table 12: HAZUS-MH Building Types



General Building Types	Specific Bubilding Types	
Concrete	Moment Frame	Low-rise
		Mid-rise
		High-rise
	Shear Wall	Low-rise
		Mid-rise
		High-rise
	Frame with Unreinforced Masonry Infill Walls	Low-rise
		Mid-rise
		High-rise
Precast	Tilt-Up Walls	
	Frames with Concrete Shear Walls	Low-rise
		Mid-rise
		High-rise
Reinforced Masonry	Bearing Walls with Wood or Metal Deck Diaphragms	Low-rise
		Mid-rise
		High-rise
	Bearing Walls with Precast Concrete	Low-rise
		Mid-rise
Steel	Moment Frame	Low-rise
		Mid-rise
		High-rise
	Braced Frame	Low-rise
		Mid-rise
		High-rise
	Light Frame	
	Frame with Cast-in-Place Concrete Shear Walls	Low-rise
		Mid-rise
		High-rise
	Frame with Unreinforced Masonry Infill Walls	Low-rise
		Mid-rise
		High-rise
Unreinforced Masonry	Bearing Walls	Low-rise
		Mid-rise
Wood	Light Frame (= 5,000 sq.	
	Commercial and Industrial Wood (>5,000	
Mobile Home	Manufactured Home	
Default	Wood	

Essential facilities are a specific group of buildings separated from the general building stock due to their criticality to the functioning of a society. HAZUS-MH classifies essential facilities as schools, hospitals and emergency response facilities such as police stations and fire stations. These buildings are defined with point-wise data and additionally qualified by seismic code level. Buildings constructed without seismic code provisions are classified as pre-code, which is the case for some structures in the Central and Eastern U.S. (CEUS). Structures with minimal seismic design receive a low-code designation, while buildings conforming to seismic code provisions are assessed moderate-code standing. Most CEUS buildings are assigned low- or moderate-code levels, with high-code reserved for the stringent seismic provisions in California. High potential loss facilities, which include dams and levees, military installations, nuclear power plants and hazardous material facilities are classified in a similar manner to essential facilities.

Transportation inventory covers numerous forms of transportation including the support facilities for these modes of transport. Various components of the transportation database in HAZUS-MH include; highways, railways, light rail, bus, port, ferry and airports. Highway systems consist of all road segments as well as any tunnels and bridges associated with them. Bridge classifications are based on National Bridge Inventory characteristics which consist of 28 bridge types. Bridge categories are based on material, construction type (simple support or continuous) and seismic design consideration. All rail and airport lifelines account for the airports and railway stations required to operate these modes of transportation. These buildings are subjected to the same seismic code level, building and occupancy types and damage state determination processes as those for buildings in the general building stock. Lastly, all water related transportation lifelines include inventory items for landings and ports, since it is unrealistic to assign damage states and losses to the rivers and waterways themselves. Each inventory item in the transportation database is defined with point-wise data, which is necessary to locate bridges on roads and ports on their respective waterways. There are cases, however, where bridges do not line up with highways. In this case the proper alignment of bridges is a task for a Level II analysis.

The final default inventory category provided in HAZUS-MH is utility lifelines. This database consists of information on the following utilities; potable water, waste water, oil (crude and refined), natural gas, electric power and communication. Each system is comprised of distribution and facility components. All types of utility systems have complete catalogs of information for maintenance and distribution facilities, wells and pumping stations, storage tanks and production plants. Distribution pipelines are not as well represented, however. Water and waste water pipelines are provided in the default inventory through estimates per census tract of brittle and ductile pipes. These estimates of pipeline can be mapped in a fashion similar to that of general building stock values. Natural gas and oil pipelines are not included in the default inventory, however general estimates of pipeline lengths are included for purposes of determining the number of breaks and leaks. The assumption used by HAZUS-MH estimates a distribution pipeline under every street, which may be an overestimation of natural gas and oil pipeline distribution. It is often the user's responsibility to specify pipeline distribution systems for these two utilities. Electric and communication utilities do not have any provisions for distribution systems within the default inventory, but rather estimations are made to account for electric distribution circuits and communications distribution to attain predictions for power and communication losses following an earthquake.

An additional inventory category is provided in which the user may specify new building types. New building types are defined with the Advanced Engineering Building Module. Point-wise data is specified as well as related building type information to be used for damage estimation. This tool is not utilized in this research and will not be discussed in detail. For further information please reference the HAZUS-MH *User's Manual: Advanced Engineering Building Module* (FEMA-NIBS, 2006).

3.4 Fragility

Fragilities represent the conditional probability of reaching or exceeding a certain damage limit state given a specific level of ground shaking. They are specified for each inventory component which includes buildings, bridges, utility network systems as well as roads and railways. Additional fragilities are included for various building contents, or non-structural components. Contents include interior walls and finishes, mechanical and electrical equipment and building contents. Only buildings appearing in the general building stock are assessed using non-structural fragilities, however. All buildings associated with transportation, utilities, etc. are not assigned non-structural fragilities. These curves are calculated using a lognormal distribution with median potential earth science hazard parameter (PGA, S_a, S_d, etc.) and standard deviation values of that parameter, μ and β, respectively. Fragility curves exhibiting lesser slopes indicate greater uncertainty of reaching or exceeding a given damage state, while greater slope indicates lower uncertainty.

HAZUS-MH defines four damage states; slight, moderate, extensive and collapse. Slight damage includes superficial or non-structural damage as well as minor cracks in structural elements, which are often referred to as an immediate occupancy limit state. This means that the structure is able to be used immediately after an earthquake. Moderate damage, or a life safety limit state, indicates more damage to structural components. This may include visible cracks in concrete or wood frame buildings and some yielding of bracing components of steel frame construction. Extensive damage, or collapse prevention limit state, includes damage to most structural components. Severe structural damage consists of significant yielding in steel members and extensive cracking of wood and concrete. Finally, complete damage implies an uninhabitable or unusable structure. Complete damage results from intense ground shaking which exists nearest the epicenter of an earthquake typically. A typical fragility curve for building structural components is illustrated in Figure 5.

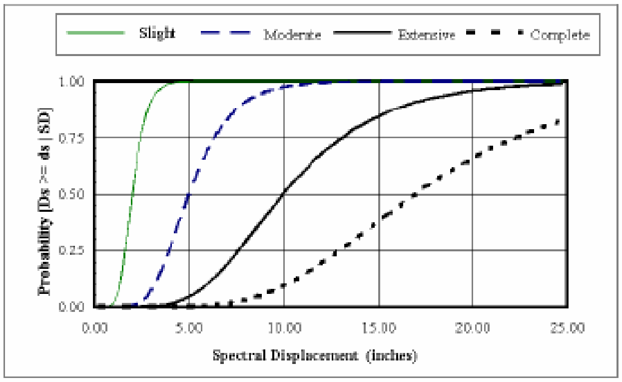


Figure 5: Typical Fragility Curve in HAZUS-MH

Damage to various infrastructure components are defined by one of several ground motion or ground deformation quantities. Within the general building stock damage states for various types of damage (structural, non-structural contents, non-structural equipment, etc.) are defined by spectral displacement, spectral acceleration, PGA or PGD. Similarly, buried tanks are affected by spectral displacement, though buried pipeline damage is determined by a combination of peak ground velocity and permanent ground deformation. The above examples highlight the variety of ground shaking parameters that are required to determine damage states to the entire infrastructure of a region. The incorporation of only one component, such as peak ground acceleration, will not provide comprehensive damage state probabilities in HAZUS-MH.

4 Project Overview

4.1 Need for Seismic Loss Assessment in CEUS

Based on previous large earthquakes experienced over the winter of 1811 and 1812, earthquake probability maps have been developed by the USGS for the NMSZ. Major epicenter locations are located in northeastern Arkansas and the southeast tip of Missouri. Greater intensities are expected near the locations of these historic earthquakes, while farther sites, such as the New England states of Massachusetts, New Hampshire and Vermont show much lower intensities, as shown in Figure 6. It is also important to note the locations of St. Louis, Missouri, and Memphis, Tennessee. Both of those cities lie in areas expected to experience strong shaking of intensity 8 and 9, respectively. Loss modeling of highway networks after an earthquake indicates significant reduction in capacity as bridges are affected and road segments incur liquefaction-induced damage (Loh et al., 2003). This form of highway network damage and reduced functionality is likely to occur in the Central and Eastern U.S. due to the presence of liquefiable soils and a nationally-significant transportation network.

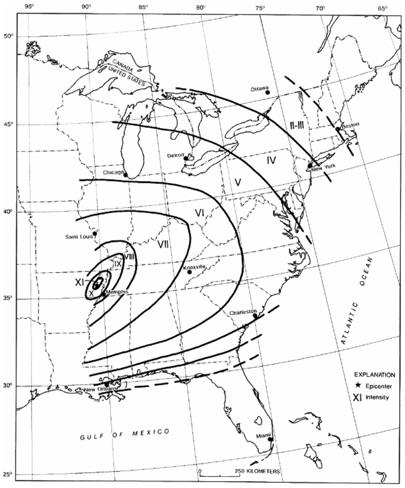


Figure 6: USGS Expected Seismic Intensity Map

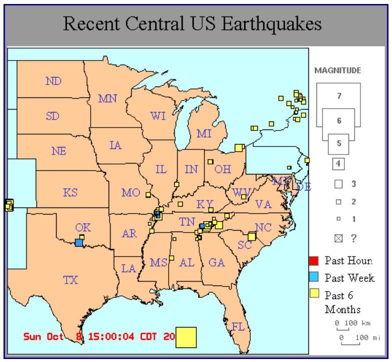


Figure 7: Recent Seismic Activity in the New Madrid Seismic Zone

The devastation brought to the Gulf Coast by hurricane Katrina in September, 2005, generated losses of roughly $125 billion (Associated Press, 2005). A repeat of the 1811 and 1812, earthquakes has the potential to cause damage significant damage and generate billions of dollars in economic losses. A comprehensive seismic risk assessment and component response and recovery plan is an economically and socially prudent choice to reduce damage levels and thus incur smaller losses and avoid the devastating losses and social impacts created by hurricane Katrina.

The Central and Eastern U.S. has not experienced earthquakes of significant magnitudes since the 1811 and 1812 events. Earthquakes of smaller magnitudes continue to occur along the presumed New Madrid Fault system. These smaller earthquakes, or magnitudes ranging from 3 to 5 (Figure 7), do not cause damage and often go unnoticed by the residents. The continuing seismic activity highlights the urgency of assessing, mitigating and planning for response and recovery from a NMSZ earthquake, the occurrence of which is not a question of 'if' but rather of 'when'.

Coordinated response and recovery plans are key to minimizing downtime and to rapid regional recovery. Previous post-hazard planning efforts have been based on expert opinions as oppose to scientifically based studies, leading to misinterpretations of hazards and subsequent post-hazard needs of victims and evacuees (Harrald & Jefferson, 2007). The results of the loss assessment conducted in this research, accompanied by results from the larger CEUS study, will provide response and recovery planners scientifically based data that more accurately depicts post-earthquake scenarios and ideally allows them to create better strategic plans and regional aid provisions. Adequate preparation may include developing host city plans for evacuees, stockpiling supplies (water, non-perishable food items, and medical supplies) and assessing the need for immediate and short-term housing for displaced residents and businesses. Coordinating government agencies with industry and volunteers prior to an earthquake will streamline response procedures and prevent some of the chaos and communication breakdowns experienced in the aftermath of hurricane Katrina.

Furthermore, the identification of vulnerable infrastructure components prior to an earthquake will allow authorities and agencies to retrofit those components (buildings, bridges, roads, and utility networks, amongst other important components) that are extremely likely to see damage and affect the performance of lifelines. With improved systems performance and fewer damaged structures it follows that fewer injuries will be sustained, post-earthquake systems functionalities will improve, and the region will experience lesser economic losses and business interruptions. The resulting loss assessment can be used as a preemptive design tool for infrastructure improvement and loss minimization; in other words, spending money for upgrades now has the potential to save more money later.

4.2 Project Objectives

The Federal Emergency Management Agency is engaged in a major catastrophic event planning initiative which includes a major hurricane in Miami, Florida, and an earthquake in the New Madrid Seismic Zone (NMSZ). The Mid-America Earthquake (MAE) Center, in cooperation with the Institute of Crisis Risk and various other contributors from the region, have been charged with undertaking a comprehensive seismic risk assessment and response and recovery plan for the New Madrid Seismic Zone. Other closely related projects are lead by the Central US Earthquake Consortium (CUSEC) and Innovative Emergency Management Inc. (IEM). The MAE Center-lead study comprises earthquake risk assessment of the eight state region in the Central and Eastern U.S. (CEUS) to earthquakes including a magnitude 7.7, located along the presumed New Madrid Fault. Other scenarios will also be developed and their impact assessed in detail, including a Wabash Valley event. These impact assessments comprise determination of damage states for numerous infrastructure components, the economic loss and social impact associated with those damage states. Specifically, this project details expected post-earthquake induced damage and social impact estimates such as locations and amounts of debris and numbers of evacuees and displaced residents due to damage or collapse of structures. Based on regional damage and evacuee estimated temporary shelter and short-term housing needs are determined and subsequently host city plans developed for evacuee shelters alongside support facilities for the evacuees. Additionally, the assessment of damage to infrastructure components is used to identify specific needs for mitigation and retrofit in order to prevent damage due to future seismic events. Finally, the risk assessment developed herein is intended to be used as outreach and education tools to encourage public awareness campaigns and initiate communication between the business and government agencies that will coordinate and conduct post-earthquake assistance and rehabilitation efforts.

The work discussed hereafter focuses on the loss assessment of a reduced region (definition of which is discussed in section 5.1) within the eight state region under investigation by the MAE Center. The selected region is that most highly impacted by a NMSZ earthquake. The major objectives from the catastrophic event planning project are refined for this reduced study to investigate the affects of various hazard and infrastructure component inventory parameters within the central portion of the NMSZ where the greatest ground motions are anticipated to occur. More specifically, the influence of soil amplification within the study region is determined, as well as its affect on damage states and corresponding economic losses to the regional infrastructure. Inventory improvements are also considered, some of which include the addition of pipeline networks for oil and natural gas as provided by the Homeland Security Infrastructure Program (HSIP) Gold Dataset which was obtained from the Office of Americas/North America and Homeland Security Division and details numerous datasets in addition to the pipeline datasets used in the current study. The issues raised, problems solved and plans developed as a result of this risk assessment and response and recovery planning effort have the opportunity to set a standard for future regional hazard assessments and cooperative emergency planning programs. The consortia assembled, the dual focus on engineering and planning, the impetus provided by FEMA and DHS and the financial commitment underpinning the current effort provide a unique opportunity not only to protect the heartland of the USA but also to set detailed and well-documented scenario-based earthquake impact assessment, response and recovery framework for future applications in other regions.

4.3 Region Background

The eight states region considered in this study is centered on the New Madrid Fault and consists of the following states; Alabama, Arkansas, Illinois, Indiana, Kentucky, Mississippi, Missouri and Tennessee (See Figure 8). These states lie along one of the United States' major waterways, the Mississippi River. Historically this river has been a critical thoroughfare for the transport of goods and workers, particularly prior to the advent of railways and vehicles as a form of mass transportation (DesRoches, 2006). As a result of the major industrial and transportation uses of the Mississippi River vast numbers of businesses and towns developed along this stretch of river in the Central and Eastern U.S.

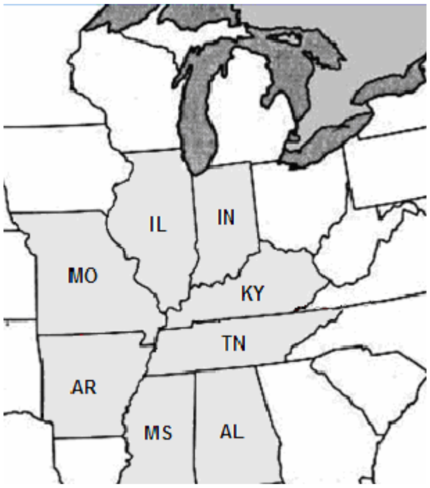


Figure 8: Central & Eastern U.S.

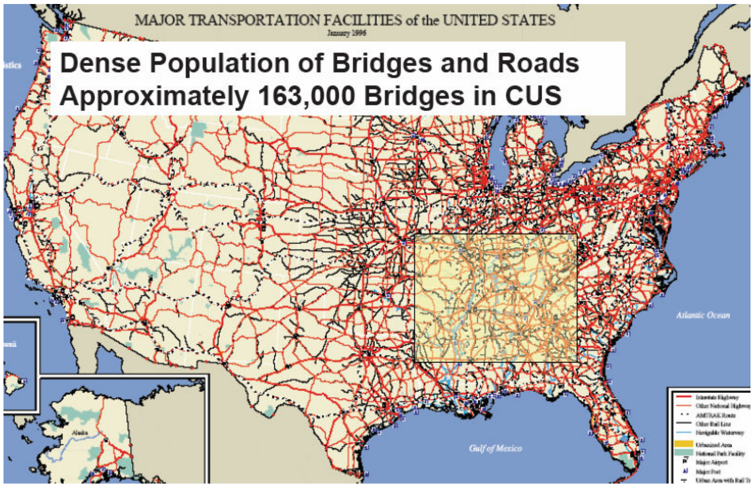


Figure 9: Highways and Bridges in the CEUS

The buildings and services that were once so intimately tied to the river transitioned to other forms of industry more appropriate and lucrative to the developing transportation centers in St. Louis, Missouri, and Chicago, Illinois. With the westward expansion of the United States in the 19th Century few large cities grew up in Midwest, making it a region known for agriculture and major industry. With few major commerce centers between the east and developing west coast, the Midwest became a region critical to the distribution of food and goods for the entire nation. Even today central U.S. highways and interstates (Figure 9) carry over $2 trillion of goods to various other regions in the country (DesRoches, 2006).

While the majority of the Central and Eastern U.S. is comprised of small towns and farming communities there are a few major cities in the region. St. Louis, Missouri, known as the ‘Gateway to the West’, which is symbolized by the famous St. Louis Arch, boasts approximately 350,000 residents while Memphis, Tennessee, houses approximately 675,000 residents based on 2005 population estimates. Other major cities include Nashville, Tennessee, Birmingham, Alabama, Louisville and Lexington, Kentucky, and Kansas City, Missouri (U.S. Census Bureau, 2006). Despite the approximately three million people living in these major cities, the majority 45 million people living in the central and eastern US live in small towns and rural areas.

The presence of the Mississippi River and its tributaries, including the Ohio, Illinois, Missouri, Rock, and Arkansas rivers, dramatically affect the geology of the CEUS study region. The soil surrounding these rivers is comprised of sediments and deep deposits of soft soils (Tsai, Park & Hashash, 2006). Not only are soft soils weak and easily compressible, but they are notorious sources of liquefaction, or the tendency of the saturated, unconsolidated soils to take on a liquid-like behavior, as in a suspension. This characteristic is especially prevalent to seismic events, as soil liquefaction frequently occurs under seismic loading. Soils lose bearing capacity and buildings shift, sustain damage or even collapse. While the mechanism and consequences of liquefaction will be discussed in greater detail in subsequent sections, it is relevant to note the importance of this regional characteristic when discussing key features of the region included in this loss assessment study.

The Central and Eastern U.S. is not widely-known as a seismically active region, such as California or Japan, though the New Madrid region has experienced major earthquakes in the past two centuries. In the winter of 1811 to 1812 three earthquakes occurred on the New Madrid Fault. According to the United States Geologic Survey (USGS) the first two earthquakes occurred in northeast Arkansas on December 16, 1811, with an estimated magnitude of 8.1. Just months later, on January 23, 1812, and February 7, 1818, two more earthquakes, with magnitudes estimated greater than 8.0, rocked southeastern Missouri. It is proposed, though unsubstantiated, that another earthquake greater than 8.0 magnitude shook southeastern Missouri on December 16, 1811. At the time of these earthquakes this region of the U.S. was not largely populated and thus the earthquakes were not well reported or strong motion effects documented. Of the minimal information collected after this series of earthquakes was evidence of landslides, mangled trees and large depressions and uplift due to ground failure (See Figure 10 & Figure 11). Despite the severity of the ground motion there were very few reported casualties and damage to man-made structures. Damage reports for that time period include the toppling of chimneys and collapse of some log cabins. In addition, uplift in Mississippi riverbed created large waves that were perceived to move upstream, and against the natural flow of the river (USGS, 2006). One area experiencing more significant damage, however; was St. Louis, Missouri. Even in 1811 and 1812, the city of St. Louis was populated with numerous homes and small businesses; a majority were wood and suffered some damage or total collapse.

Figure 10: Mangled Trees Resulting from New Madrid Earthquakes

Figure 11: Landslides Caused by New Madrid Earthquakes

Reports from this time also indicate that ground motions resulting from the New Madrid earthquakes were felt as far away as Washington, D.C., and Charleston, South Carolina (CUSEC, 2006). The far-reaching shaking felt on the east coast is due, in part, to the type of soil in the New Madrid Seismic Zone, and the Mississippi Embayment, which allows for the amplification of motions as specific frequencies to transmit farther. When a weaker, magnitude 6.0 earthquake from 1895 in the CEUS is compared to a stronger, magnitude 6.7 earthquake in California from 1994, the difference in attenuation distances is obvious. Strong motions from Central and Eastern U.S. earthquakes have a far greater capacity to affect areas hundreds of miles away, as oppose to those on the west coast with more localized damage regions (See Figure 12).

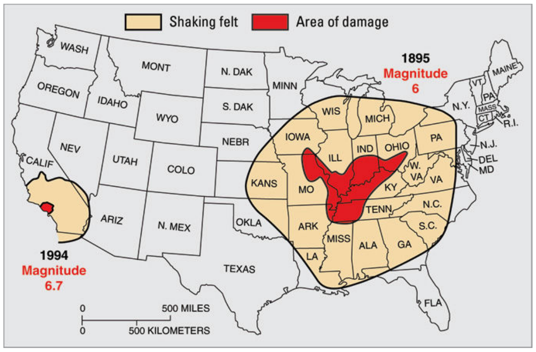


Figure 12: Attenuation Comparison for New Madrid Seismic Zone

A lack of seismic design provisions allowed decades of construction without regard for seismic detailing and energy dissipation capability. What this means is that the Central and Eastern U.S. has hundreds of thousands of wood and masonry building reminiscent of those that collapsed during the 1811 and 1812 earthquakes. Though current construction adheres to more stringent design guidelines seismic provisions are still lacking. Unreinforced masonry buildings, in particular, are likely to sustain damage with moderate levels of shaking (Moon et al., 2001), thus reducing the capability of emergency response personnel and endangering numerous school children. Injury and casualty levels were investigated by FEMA in a baseline study of an earthquake on the northeast extension of the New Madrid Fault which indicates the prevalence of unreinforced masonry buildings (URMs) as a critical factor in terms of serious and loss of life injuries.

Table 13: Casualties in Unreinforced Masonry Buildings

No. of Level 2,3,4 Casualties	Night Time (2am)	Day Time (2 pm)	Commuting (5 pm)
Without URMs	1,750	3,750	5,500
With URMs	16,500	16,550`	17.300
% Caused by URMs	**89%**	**77%**	**68%**

According to the FEMA study (Bausch, 2006) there are approximately 450,000 unreinforced masonry buildings in roughly 2,500 census tracts centered on the New Madrid Fault. Based on the casualty data reported by Bausch (HAZUS Applications, 2006), it is evident that the majority of serious injuries and fatalities in a New Madrid earthquake can be attributed to the damage or collapse of URMs. The vulnerability of URMs is substantiated by South Carolina researchers, as they also report poor seismic design performance for the low-rise unreinforced masonry structures that are common in both central and eastern U.S. regions (Wong et al. 2005). This data alone posed strong evidence for the prioritization of URM retrofits to reduce injures and fatalities in the CEUS, as well as illustrating the need for seismic design provisions to ensure that URMs are no longer constructed. The work of Moon et al. (2001) also highlights the benefits and improved seismic performance of retrofitted URM structures. It follows then that reduced damage will reduce the injuries related to this type of structure.

4.4 Parameters for the Loss Assessment Study

An initial Level I analysis is completed to illustrate regional damage, loss and functionality with default inventory, hazard and fragility data. Three earthquake scenarios are analyzed at this basic level of analysis and are used for later comparison with improved regional models. An improved Level I analysis is also carried out. This set of three analyses, one for each epicenter, is conducted with improved soil classes only. Regional ground motion is modified based on the regional site classes to reflect more accurate regional propagation of ground motion. These two levels of analysis lead to the final level, Level II, which is the main focus of regional damage, loss and functionality.

The most improved loss assessment undertaken in this research focuses on a Level II HAZUS-MH analysis. Improvements to default hazard and inventory data focus on site characteristics, ground motion attenuations as well as the addition and upgrade of several inventory components. Regional site class and liquefaction susceptibility maps are incorporated into the determination of ground motion response. Ground motion is assessed for a given epicenter outside of HAZUS-MH through the development of hazard maps for peak ground acceleration (PGA), peak ground velocity (PGV), spectral acceleration at 0.2 second period and spectral acceleration at 1.0 second period to avoid attenuation limitations present within HAZUS-MH. A set of hazard maps is created of the default site class and improved site classes for a given epicenter. Liquefaction susceptibility information is incorporated within HAZUS-MH in conjunction with hazard maps for improved site classes. The procedure through which hazard maps are created is not detailed here as it is discussed in much greater detail in subsequent sections.

Major inventory upgrades include the addition of utility pipeline networks. The MAE Center obtained a copy of the Homeland Security Infrastructure Program (HSIP) Gold Dataset for 2005 which is distributed by the Office of Americas/North America & Homeland Security Division. This compilation of information contains over 200 data sets for numerous infrastructure components based on use or occupancy. For example, the data set contains information on theaters, schools, state capitals, major manufacturing and utility facilities, utility networks, transportation facilities, hazardous material facilities, in addition to locations of major natural resources and their controlling mechanisms (locks, dams, levees, etc.) Each dataset details the location, contact information and some facility statistics (number of stories, construction year, etc.) for each list item. While the amount of data that can be drawn from this dataset is expansive only natural gas and oil pipeline datasets are chosen for this project. These data items are not part of the default inventory in HAZUS-MH and will supplement the assumed inventories for water and wastewater pipelines within the program already.

Level II analysis also includes the incorporation of updated fragility curves. The MAE Center developed 36 sets of parameterized building fragility curves for the 36 specific building types in HAZUS-MH (FEMA-NIBS *User's Manual*, 2006). Each set of fragility curves defines the probability of each building type reaching or surpassing each of three limit states; collapse prevention, life safety and immediate occupancy, as a function of spectral acceleration (Jeong & Elnashai, 2006). There is also work within the MAE Center to develop fragilities for various bridge types that will eventually be introduced into the HAZUS-MH fragility framework. Despite the capability of HAZUS-MH to recognize and evaluate damage based on improved fragilities this form of analysis is not undertaken in this research due to time constraints. Updated fragilities will be considered in later loss assessment studies related to the CEUS.

4.5 FEMA Baseline Study

The Federal Emergency Management Agency completed a baseline seismic loss assessment study for a region in the Central and Eastern U.S. centered on the New Madrid Fault. This study region is comprised of 2,517 census tracks in the same eight states as those in the general area of interest for this project. Figure 13 details the extent of the region analyzed in the baseline study. Three hazard scenarios are included in this study with fault ruptures located along the northeast, central and southwest extensions of the New Madrid Fault. For fault extension locations reference Figure 21. Each fault extension is estimated to experience a magnitude 7.7 earthquake, which is the generally accepted magnitude for the New Madrid Fault as determined by the USGS and are estimated to resemble the level of the 1811 and 1812 earthquakes along the New Madrid Fault (Bausch, 2006).

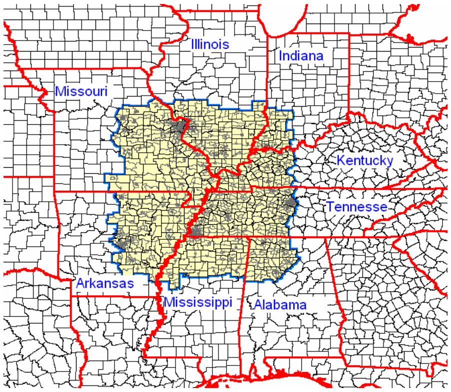


Figure 13: FEMA Baseline Study Region

Hazard maps are generated outside of HAZUS-MH and imported for ground response parameters, PGA, PGV, S_a at 0.3 seconds and S_a at 1.0 (See Figure 14 & Figure 15) seconds as required by HAZUS-MH for proper determination of damage states results based on ground motion. When computing ground motion values the USGS did consider the affect of site class on the amplification or reduction of these response parameters. The USGS also considered the affects of liquefaction on seismic response and related permanent ground deformations due to liquefied soils. Liquefaction susceptibilities were developed from site class maps compiled by state geologists for the Central United States Earthquake Consortium (CUSEC). The greatest liquefaction susceptibility is illustrated by the areas showing a level 5 in Figure 16, and classified as "Very High" susceptibility. Lesser numbers indicate lower levels of liquefaction susceptibility until reaching no susceptibility at a value of "0." The liquefaction susceptibility map used by FEMA shows high liquefaction susceptibilities in and around the riverbeds of local rivers as well as within the Mississippi Embayment, which is depicted by the greens appearing in the southern portion of the map. The development procedures and resulting accuracy of the liquefaction susceptibility values have been questioned by various agencies thus correcting these values is one of the primary goals of future loss assessment hazard definition in the CEUS.

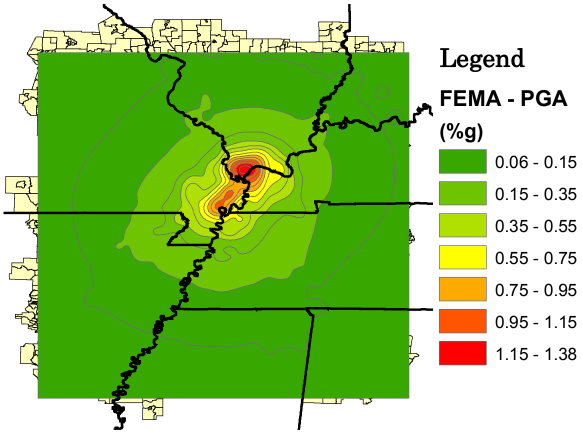


Figure 14: USGS PGA Hazard Map NE

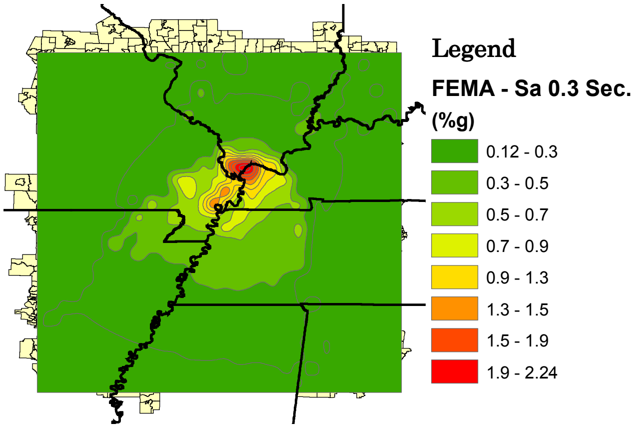


Figure 15: USGS Sa 0.3 Sec. Hazard Map NE

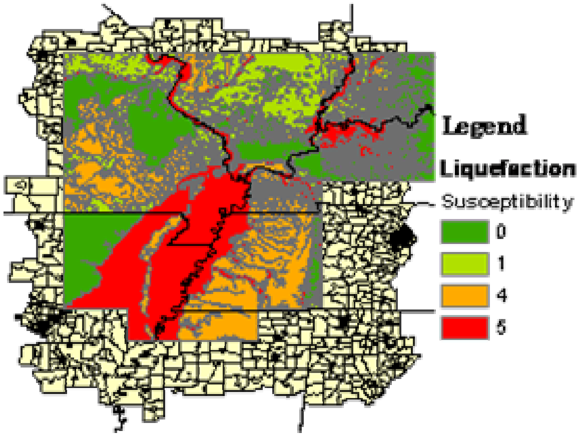


Figure 16: USGS Liquefaction Susceptibility Map

No additions to regional inventory were made in the baseline study though some updated inventory data was included in the HAZUS-MH region file for this study. Default pipeline assumptions can be supplemented by supplying natural gas and oil transmission and trunk line data to the study region. Specifying this supplemental data overwrites assumptions of local distribution pipeline layouts and also the breaks and leaks associated with those lines. These larger lines, however; carry much greater capacities than the smaller local lines and also provide definitive locations for each lifeline distribution system. See Figure 17 for the layout of both pipeline distribution systems. This accuracy in inventory reporting is the goal of upper level analyses in HAZUS-MH, and thus the lack of local pipeline assumptions is allowed. This data was obtained from the HSIP Gold dataset distributed by the Office of Americas/North America and Homeland Security Division, which also details numerous other datasets and is discussed in greater depth elsewhere in this research.

It is also relevant to note several other analysis parameters used in the FEMA baseline study. All population demographic data are drawn from the year 2000 census data. No updated estimates of population were incorporated during this study. Moreover, this regional analysis was conducted using the MR1 release of HAZUS-MH, in which replacement costs for all buildings are based on 2002 per square foot replacement costs as dictated in the 2002 volume of *R.S. Means*. The latest release of HAZUS-MH MR2, also employs replacement costs that are based on 2002 per square foot costs from *R.S. Means* (FEMA-NIBS, *User's Manual*, 2006). As a result of these outdated replacement costs estimated repair costs and economic losses attributed to building stock will not reflect inflation over the period of 2002 to the present.

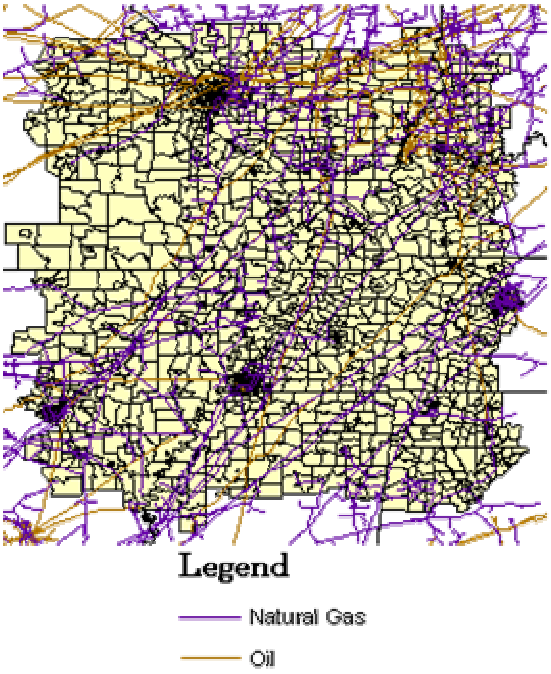


Figure 17: Regional Oil & Natural Gas Pipelines

The combination of improved hazard and inventory items are filtered into HAZUS-MH and three scenarios analyzed within the scope of the FEMA baseline study. Each fault extension was analyzed for determination of damage and losses as a function of fault rupture. Particular areas of interest included economic losses related to buildings, transportation and utility systems, as well as the affect of liquefaction susceptibility on damage for each of the three epicenter locations. Total economic losses were calculated for each epicenter to determine an overall worst case scenario. The results and findings of this study will be detailed in subsequent sections, where they are also compared to the findings of this research.

5 Project Scope and Procedure

5.1 Region Definition

The risk assessment study conducted in the CEUS focuses on eight states within the New Madrid Seismic Zone; Alabama, Arkansas, Illinois, Indiana, Kentucky, Mississippi, Missouri and Tennessee. Several levels of study region refinement are defined within the broad scope of the regional risk assessment being conducted by the MAE Center. The most detailed level consists of five locals assessments for two major urban centers; St. Louis, Missouri, and Memphis, Tennessee, as well as three rural communities; Cairo, Illinois, Wickliffe, Kentucky, and Charleston, Missouri. The locations of these local studies are illustrated in Figure 18. State-wide risk assessments comprise the second level of region refinement. Individual state assessments are designed to provide each CEUS state with a worst-case earthquake scenario and loss estimation for their own preparedness efforts. Lastly, a regional assessment consisting of all eight states define the final level of analysis (Figure 19). From this broad region a smaller area within the CEUS states is defined based on threshold ground shaking parameters, such as peak ground acceleration.

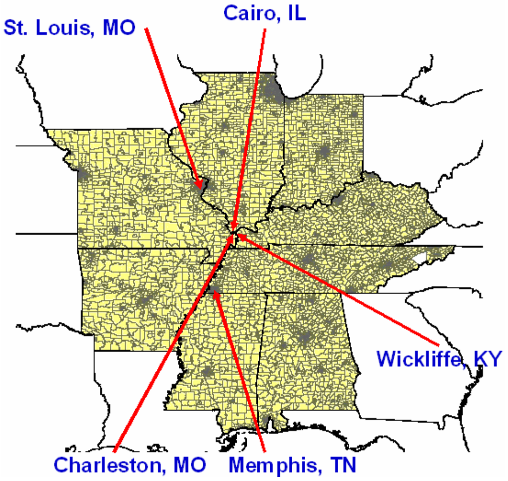


Figure 18: CEUS Local Risk Assessment Locations

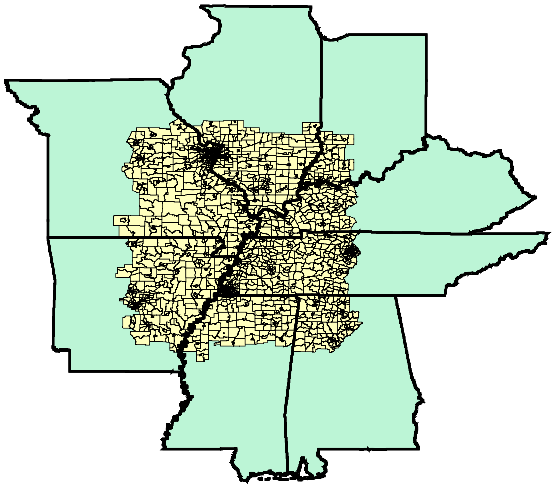


Figure 19: Extent of Regional Risk Assessment

Additional criteria for study region determination in this loss assessment are taken from the FEMA baseline study. The extents of the region used in the FEMA loss assessment are illustrated previously in Figure 13. Region determination for the FEMA study employed a 0.05*g* PGA threshold value. All counties appearing in the study region are expected to experience 0.05*g* PGA, or greater, when any of three earthquake scenarios are applied to the area (epicenters along northeast, central and southwest extension of New Madrid Fault). One of the PGA shake maps used to establish regional boundaries appear in the previous illustration, Figure 14.

At this juncture in the region determination process is it exceedingly relevant to consider the region size limit inherent in the basic use of HAZUS-MH. The default server used for all regional damage and loss processing within HAZUS-MH only permits the use region files that require less than two gigabytes (2GB) of information, which equates to approximately 2,000 census tracts for the earthquake model. The entire eight state region consists of more than 10,200 census tracts, which far surpasses the default server's processing capabilities. FEMA's reduced region comprises only 2,500 census tracts, roughly. Though this amount of census tracts exceeds the recommended region limits, HAZUS-MH was still able to process the region and all file attachments, though the performance of the program decreases significantly due to the large region size. Region sizes exceeding 2GB can be processed through the use of a new server, SQL Server 2000 (FEMA-NIBS, *User's Manual,* 2006). At the time this research began SQL Server 2000 was not available and thus region sizes were limited to approximately 2,000 census tracts.

Based on the scope of the CEUS loss assessment, the regional criteria and boundaries employed in the FEMA baseline study and the study area limitations inherent in HAZUS-MH a study region for this research is determined. The study region used in this research is similar to that used in the FEMA baseline study, though reduced by over 500 census tracts. Reference Figure 20 for comparisons between CEUS, FEMA and newly defined regional boundaries. The largest region, in blue, details the CEUS region comprised of all eight states. The tan region highlights the extents of the FEMA baseline study region. Considering the threshold value of 0.05*g* defines the boundary of the FEMA region, the remaining portion in the CEUS region, nearly 8,000 census tracts, is expected to experience minimal shaking due to an earthquake on the New Madrid Fault according to FEMA. The central green portion illustrates the area investigated in preliminary research. The tan FEMA baseline region is chosen for this study which provides an identical basis for comparison. According to the hazard maps associated with this region the PGA threshold value that roughly defines the regional boundary is 0.06*g*.

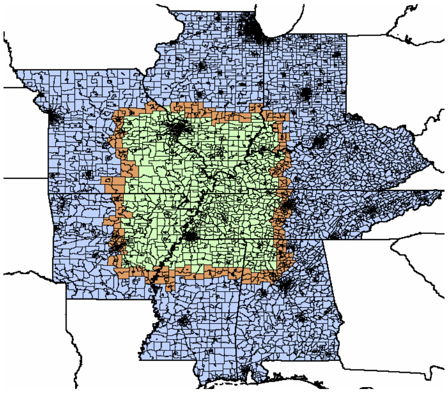


Figure 20: Region Size Comparison

5.2 Hazard Definition

Due to the geometry and length of the presumed New Madrid Fault several epicenters are evaluated along the fault to determine a worst-case scenario over its entire reach. Three epicenters are chosen, two representing the extreme northern and southern ends of the proposed fault, on one centrally located epicenter. As mentioned previously, there are three proposed locations of New Madrid Fault which comprise the larger New Madrid Seismic Zone. The northern most epicenter, hereafter referred to as the Northeast (NE) epicenter, sits on the northern most point of the northern most fault. A second hazard scenario, hereafter referred to as the Central epicenter, is defined along the central thrust of the proposed middle fault line and appears in northwestern Tennessee. Yet another epicenter is located at the southern most extent of the south fault in northeast Arkansas and hereafter referred to as the Southwest (SW) epicenter. The locations of each proposed fault line appear in red and epicenter locations are illustrated by blue dots in Figure 21. The northeast epicenter will elicit damage as far north as relevant attenuations will allow. Similarly the southwest epicenter will account for damage due to an earthquake occurring on the extreme southern reach of the fault. All other events occurring in between these extreme locations are encompassed by the Central fault which estimates damage to areas centrally located along the fault system. Epicenter locations are as follows:

Table 14: Epicenter Locations

Epicenter Name	Latitude	Longitude
Northeast (NE) Epicenter	37.189521 N	-89.38144 W
Central Epicenter	36.36318 N	-89.5768 W
Southwest (SW) Epicenter	35.181592 N	-90.415265 W

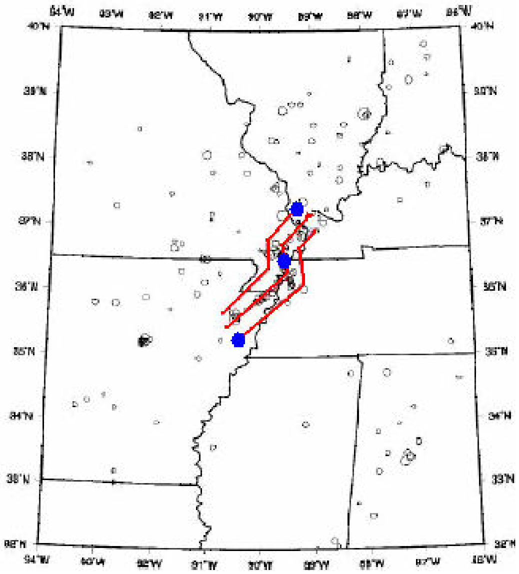


Figure 21: Proposed New Madrid Fault and Epicenter Locations

There are infinite locations where epicenters can be placed and sensitivity analyses performed, however; with the three scenarios used in the baseline study in mind, three epicenters is determined to be an adequate number to represent the possible hazard within the study region. With epicenter coordinates defined the hazard due to earthquake at each location is determined. As discussed in the previous section on HAZUS-MH methodology the point-source epicenter option for hazard definition within HAZUS-MH assigns a maximum attenuation distance of 200km to any point-source event. The region under investigation here exceeds the attenuation limit, and thus assigns ground motion parameters of zero to southern portions of the region when the NE epicenter is used, as seen in Figure 22. Non-zero ground motion values exist beyond the 200km limit and the arbitrary assignment of a cut-off distance in HAZUS-MH yields, not only an inaccurate representation of the ground motion at distances greater than 200km, but also assigns random values for damage state probabilities. This random assignment is most evident in essential facility damage state estimations. A hospital or school, for example that lies farther than 200km from a given epicenter is likely to experience minimal ground motion and incur little to no damage. HAZUS-MH, however; may assign a 60%, or higher, probability of extensive damage or collapse. It is intuitive that such severe damage states will not actually occur when a given structures experiences less than 0.05*g* PGA or spectral acceleration. Abnormally high probabilities of severe damage are incorporated into the determination of economic loss despite their inaccuracies, and leads to excessive regional economic loss values for essential facilities, as shown in Figure 23.

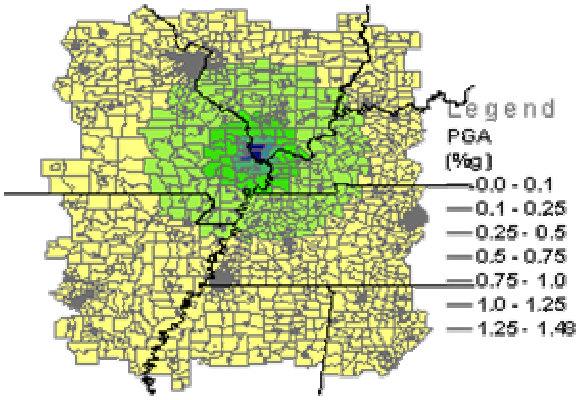


Figure 22: Study Region with Attenuation Limit

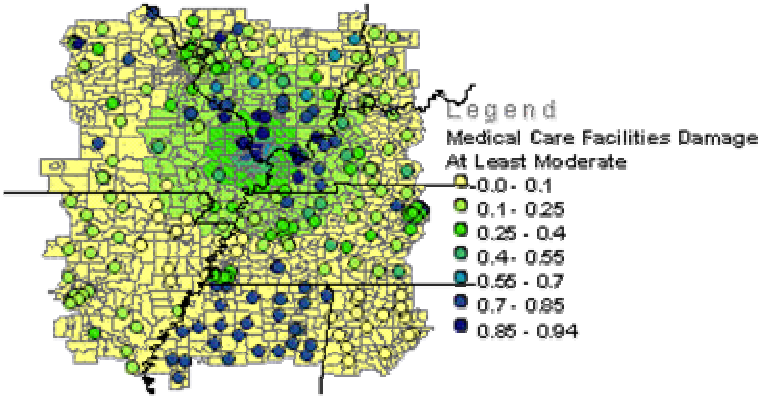


Figure 23: Essential Facilities Damage with Cut-Off Distances

This problem is compounded when damage state values are incorporated into the post-earthquake functionality of essential facilities lying more 200km from the epicenter. It seems logical that building experiencing negligible ground motion will not be severely damage and thus functional immediately after or within days of an earthquake. When random damage states are assessed to these structures, however; HAZUS-MH predicts that structures experiencing no ground motion will not be function until weeks after an earthquake (See Figure 24). Essential facilities functionalities are then represented inaccurately due to the random assignment of damage states. In order to remedy this problem and provide accurate ground motion values to census tracts lying farther than 200km from an epicenter, the HAZUS-MH attenuation methodology is applied outside the program itself to develop ground motion maps which are then applied to HAZUS-MH as a predefined hazard.

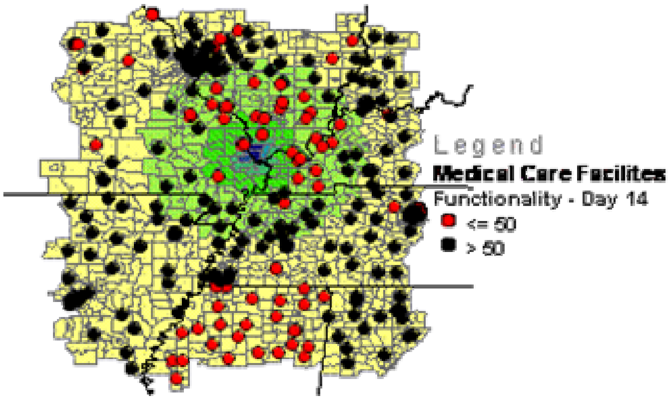


Figure 24: Emergency Care Facilities Functionality

5.2.1 Hazard Map Development

The development of hazard maps follows the HAZUS-MH methodology for ground motion determination, though permits the attenuation of response values beyond 200km. As mentioned in the HAZUS-MH methodology section, there are two sets of attenuation functions that apply to the Central and Eastern U.S.; the CEUS Event and the CEUS Characteristic Event. Both sets of attenuations are applicable to the New Madrid Seismic Zone so the CEUS Event, with four contributing attenuations, is chosen to represent overall ground motions for this study region.

A program was developed using Matlab 7.0 Version 4 which incorporates the necessary attenuations and census tract centroid distances to determine various seismic response parameters. Developed in the MAE Center (Lafore, 2006), the ground motion program permits the addition of site class information and response amplification or reduction based on *National Earthquake Hazards Reduction Program (NEHRP) Provisions* for site class (*FEMA 450*, 2003). Each attenuation also requires a depth to epicenter distance, which is used in conjunction with the surface distance to calculate each response parameter for each census tract in a given study region. HAZUS-MH employs a default depth of 10km to the CEUS Event, and this assumption is carried through in the determination of ground motion conducted herein.

Prior to the calculation of ground motion outside HAZUS-MH a preliminary ground motion analysis is carried out within HAZUS-MH. While the seismic response parameters are not used, this step is essential to the establishment of an epicenter and the distances to census tract centroids within the study region. If the HAZUS-MH default site class, D, is sufficient then the preliminary analysis requires no additional map attachments. If improved site classes must be accounted for in the hazard maps to be developed, however; a map detailing the site class assignments within the study region must be attached at this stage and prior to the determination of preliminary ground motion. Once the proper site class information is incorporated HAZUS-MH performs an analysis of ground motion values only. The resulting information is then exported as a text file from the 'Attribute Table' of any mapped ground motion parameter and then opened in a spreadsheet program, such as Microsoft Excel. The 'Attribute Table' details numerous quantities for every census tract within the study region, though the only parameters of interest are the census tract number, distance and soil class columns. These three sets of values are placed in a new text file which is read into the Matlab ground motion program.

HAZUS-MH requires four hazard maps when using the User-Supplied Maps option to define an earthquake; PGA, PGV, and spectral acceleration at 0.3 second and 1.0 second periods. Running the ground motion calculator in Matlab will provide the required response values for each census tract, which are copied into yet another text file. The new text file with Matlab output lists input parameters; census tract, distance and site class, as well as all output parameters. User-Supplied hazard maps read in each parameter type (PGA, PGV, etc.) according to a parameter heading, "PARAMVALUE," thus requiring each response parameter to have its own text file with each of the four parameters displaying the heading, "PARAMVALUE." These four text files must be saved as comma separated value (.csv) files to ensure compatibility with ArcGIS programs.

ArcMap, a facet of ArcGIS, is used to develop the shapefiles required for later creation of a geodatabase of hazard maps. A copy of the “hzTract” file, within the “RegionBndry” geodatabase for the study region, is opened in ArcMap with subsequent application of a data layer containing the newly created .csv file for a single response parameter (PGA, etc.). The joining function in ArcMap is utilized to join the “hzTract” file with the ground motion file based on the census tract values in each ArcMap layer. Successful joining of the two files is ensured by the appearance of the chosen response value column heading appearing as “PARAMVALUE” and all the values in that column displaying non-“Null” values, meaning the numeric values associated with the response parameter and the corresponding census tract. The updated “hzTract” file is exported as a shapefile and appears in the same location (folder) as the response file (PGA, etc.) in ArcCatalog. Completion of this joining process for PGA, PGV, Sa at 0.2 sec. and Sa at 1.0 sec. provides the needed shapefiles, however; this format is not supported by the HAZUS-MH platform. The final step of hazard map creation requires the creation of a new geodatabase where are all shapefiles are exported. The maps in the geodatabase are added into HAZUS-MH where the User-Supplied Hazard option is used to define the new hazard maps. Mapping the newly defined hazard values in HAZUS-MH illustrates the lack of cut-off distance and full attenuation of ground motion, as seen in Figure 25.

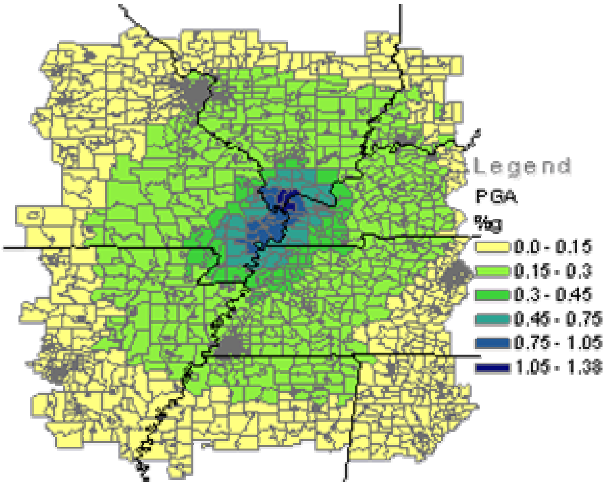


Figure 25: User-Supplied PGA Hazard Map for NE Epicenter (Site Class D)

5.2.2 Accuracy of Hazard Maps

While the accuracy of the ground motion generation program was verified for the CEUS Event by its developer ensuring the accuracy of the ground motion used for any analysis is critical step. Determination of HAZUS-MH ground motion is accomplished through a supplementary analysis using an arbitrary event at the same epicenter selected for previous hazard maps development. Since default site classes are used for the aforementioned set of hazard maps, attenuation functions form concentric circles that emanate from the epicenter, thus permitting a straight-forward comparison of ground motion parameters. Figure 26 - Figure 29 illustrate the relationship between HAZUS-MH ground motion and the externally derived ground motion. Peak ground acceleration values are considerably larger using the HAZUS-MH ground motion for distances less than 50km. A maximum PGA value of roughly 1.5*g* is determined by HAZUS-MH, whereas the external hazard shows a maximum PGA value of approximately 0.9*g*. Peak ground velocity shows similar trends to PGA, with discrepancies of several inches per second between HAZUS-MH and user-supplied hazards. Again, HAZUS-MH provides a much higher estimate of maximum PGV nearest the epicenter, by nearly 17 in./sec.

The short-period spectral acceleration responses show similar values within 20km of the epicenter, short-period response appears to provide the same acceleration value, or nearly, up to the cut-off distance. The one second spectral acceleration does not compare as well, though. With the exception of the distance range of 140km to 200km from the epicenter, the HAZUS-MH S_a 1.0 second values are much higher than the user-supplied values. With the accuracy of the ground motion generation program assured by hand calculations completed by the developer prior to its distribution, HAZUS-MH appears to overestimate the hazard within the attenuation range, particularly near the epicenter. Additionally, the attenuation functions incorporated into the CEUS Event are exponentially decreasing functions, which should result in smooth curves, such as those seen for the user-supplied hazard. The HAZUS-MH ground motion curves show breaks or jumps in the curves that can not be attributed to any particular cause due to the 'black box' nature of HAZUS-MH coding. With these concerns regarding the HAZUS-MH ground motion determination in mind, and the accuracy checks completed for the external hazard generation program, the user-supplied hazard maps are determined to be accurate representations of regional ground motion without overestimation of shaking.

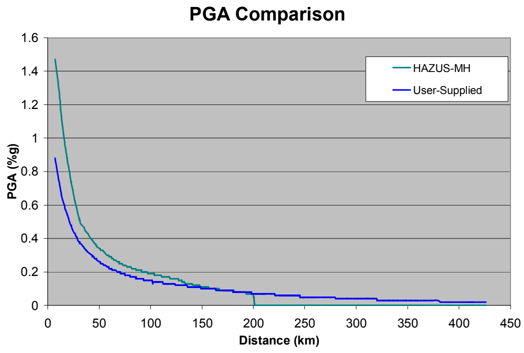


Figure 26: PGA Comparison

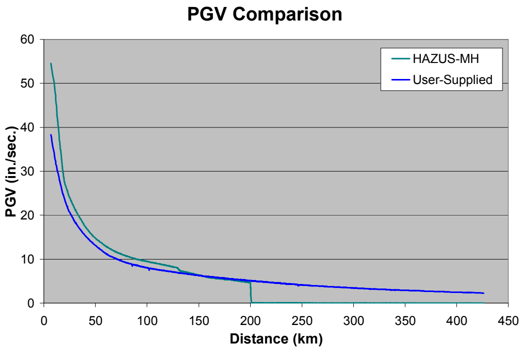


Figure 27: PGV Comparison

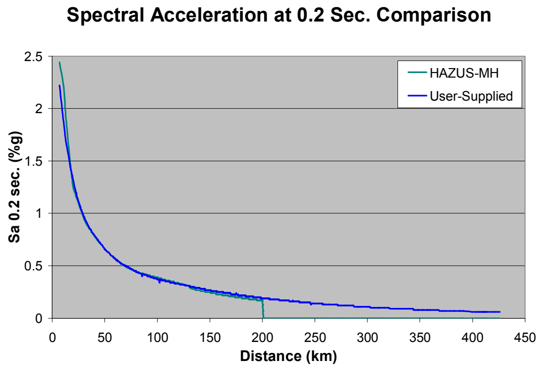


Figure 28: Sa 0.3 Sec. Comparison

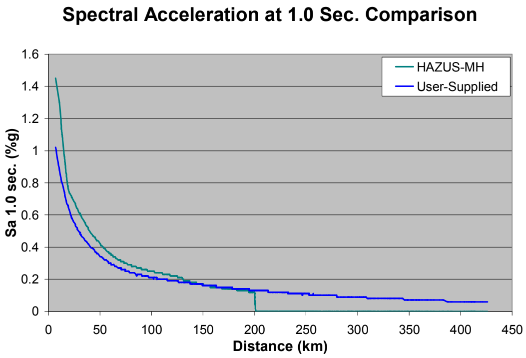


Figure 29: Sa 1.0 Sec. Comparison

5.2.3 Incorporation of Site Classification

Hazard determination for the default site class requires the integration of the four CEUS Event attenuation functions only, whereas improving the hazard to account for site class necessitates the inclusion of NEHRP provisions for site response. Adjustments are made only to portions of the region assigned site classes ‘A,’ ‘B,’ ‘C’ and ‘E.’ Any region assigned site class ‘F’ must be adjusted to site class E because HAZUS-MH does not recognize site class ‘F’ as there are no NEHRP site class factors for soils in this category. Figure 30 details the portions of the study region where improved site class information is available. Approximately 80% of the study region is covered by the improved site class map, which leaves only a small portion of the region defined by the default site class, ‘D.’

Amplification and reduction factored associated with the map of improved soil types are calculated based on the procedure outlined in the *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures* (FEMA 450, 2003). Determinations of acceleration parameter response are based on a maximum considered earthquake which is a magnitude 7.7 event for NMSZ region. The maximum spectral accelerations, S_{MS} and S_{M1}, are calculated for each census tract in the study region based on the following:

$$S_{MS} = F_a * S_s \quad \& \quad S_{M1} = F_v * S_1$$

where S_S = The short period maximum spectral acceleration response at 5% damping

S_1 = The one-second period maximum spectral acceleration for at 5% damping

F_a = The short period site coefficient (at 0.2 sec. period)

F_v = The long period site coefficient (at 1.0 sec. period)

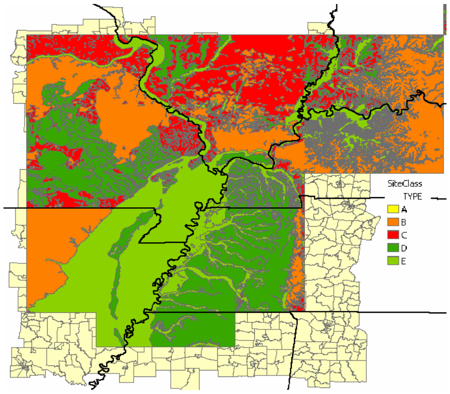


Figure 30: Improved Site Class Map

Both site coefficients are found in table for short and long period responses, respectively, and dependent on the value of corresponding spectral acceleration period value. Site coefficients, F_a and F_v, are determined via Table 15 & Table 16. In cases when the response value does not appear in one or both of the tables, for example $S_S = 0.45g$, linear interpolation between spectral values is used to determine the appropriate coefficient(s).

Table 15: Site Coefficient, Fa, for Short Period Spectral Acceleration (FEMA 450, 2003)

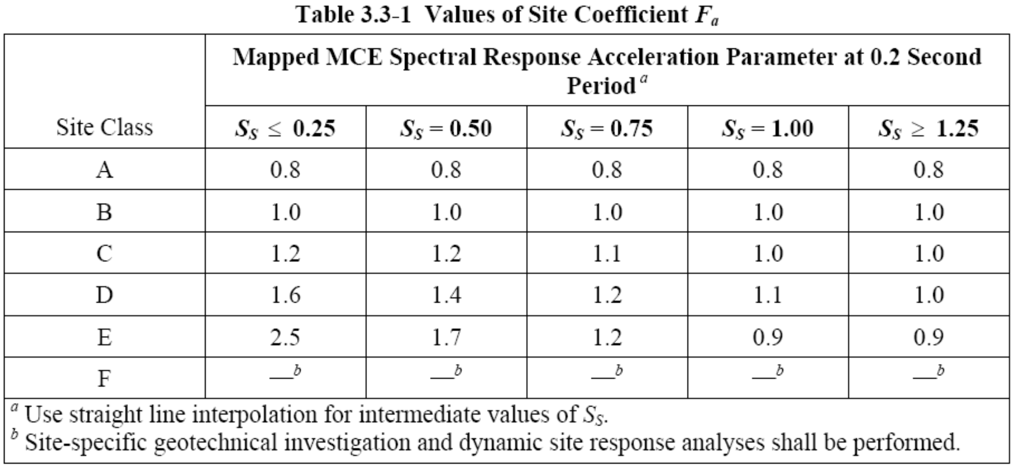


Table 3.3-1 Values of Site Coefficient F_a

Site Class	**Mapped MCE Spectral Response Acceleration Parameter at 0.2 Second Period** [a]				
	$S_S \leq 0.25$	**$S_S = 0.50$**	**$S_S = 0.75$**	**$S_S = 1.00$**	**$S_S \geq 1.25$**
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	—[b]	—[b]	—[b]	—[b]	—[b]

[a] Use straight line interpolation for intermediate values of S_S.
[b] Site-specific geotechnical investigation and dynamic site response analyses shall be performed.

Table 16: Site Coefficient, Fv, for Long Period Spectral Acceleration (FEMA 450, 2003)

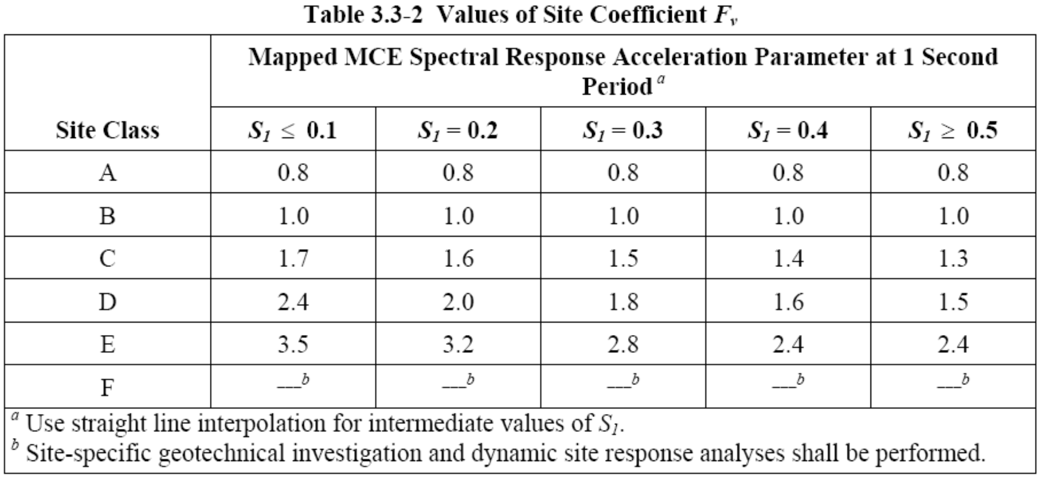


Table 3.3-2 Values of Site Coefficient F_v

Site Class	**Mapped MCE Spectral Response Acceleration Parameter at 1 Second Period** [a]				
	$S_1 \leq 0.1$	**$S_1 = 0.2$**	**$S_1 = 0.3$**	**$S_1 = 0.4$**	**$S_1 \geq 0.5$**
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	—[b]	—[b]	—[b]	—[b]	—[b]

[a] Use straight line interpolation for intermediate values of S_1.
[b] Site-specific geotechnical investigation and dynamic site response analyses shall be performed.

Once the site coefficients are determined the spectral acceleration value is multiplied by the factor and a new spectral value, more representative of actual soil response, is calculated.

Peak response parameters, PGA and PGV, are also evaluated using the NEHRP site coefficient method. Since PGA represents the ground motion at a spectral acceleration of zero-period, the short period coefficient is applied, and the value is modified in the same manner as the short period spectral acceleration. Peak ground velocity, however; is calculated using the long period spectral acceleration in CEUS Event attenuation functions and thus modified by the factor, F_v, applied to the one-second period spectral acceleration.

The NEHRP ground motion modification factor for site class used to develop hazard maps for the NMSZ employ a short-period of 0.2 seconds, as discussed previously. HAZUS-MH, however; calculated short-period spectral values at a period of 0.3 seconds. Subsequently, all damage state determinations for infrastructure components are based on the greater short-period, 0.3 sec. This difference of 0.1 seconds between periods is not problematic due to the shape of the spectral acceleration response curve as it relates to structural period. Design spectral accelerations, S_{DS} and S_{D1}, are reductions to the maximum expected spectral accelerations for the purposes of structural design. As illustrates in the equations below the maximum spectral values are reduced by a factor of one-third, which implies the spectral values structures are expected to experience is two-thirds of the predicted values for the maximum considered earthquake.

$$S_{DS} = \frac{2}{3} * S_{MS} \;\;\&\;\; S_{D1} = \frac{2}{3} * S_{M1}$$

where; S_{DS} = The design spectral acceleration for short-period response

S_{D1} = The design spectral acceleration for one-second period response

The design spectral accelerations are then used to determine the range of period values over which the short period spectral acceleration applies. Boundary values of period for short-period spectral acceleration applicability are calculated as follows:

$$T_0 = 0.2 * \frac{S_{D1}}{S_{DS}} \;\;\&\;\; T_S = \frac{S_{D1}}{S_{DS}}$$

Both periods of interest, 0.2 seconds and 0.3 seconds, fall within the range of T_0 to T_S, thus permitting the use of short-period acceleration for either period value, as seen in Figure 31. Over the range of T_0 to T_S the spectral acceleration is constant at the short-period acceleration, meaning the same spectral response value will be assigned to any structural period within that range. As a result of this constant spectral acceleration the determination of damage states in HAZUS-MH will not be affected by the shorter period employed in the NEHRP specifications and the CEUS Event attenuations.

A census tract analysis is performed to check the accuracy of response parameter adjustment based on the aforementioned NEHRP site class factors for PGA, PGV and both spectral acceleration values. Comparisons show that ground motion is amplified considerably for site class ‘B,’ with increases in PGA as much as 1.8 times larger than the

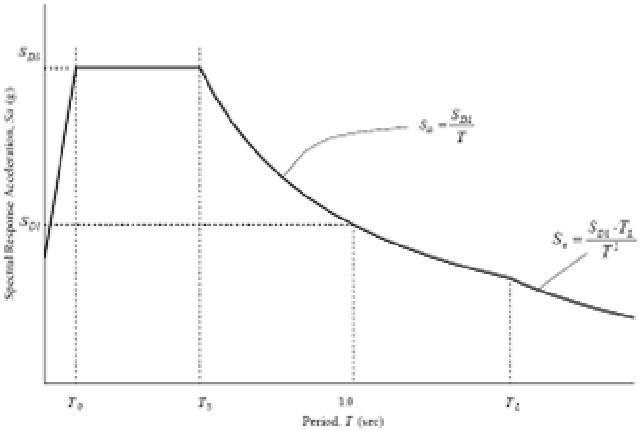


Figure 31: Spectral Acceleration vs. Period (FEMA 450, 2003)

PGA for site class 'D.' Short-period spectral acceleration increases similarly to PGA, though PGV and long-period spectral acceleration values increase as much as 2.67 times that of site class 'D' values. Site class 'C' shows a much lower increase in ground motion values, approximately 10-40% for all response parameters. As is expected site class 'D' response values remain unaltered when compared to the default analysis. Decreases in ground motion values of up to 33% are present in site class 'E.' This is especially relevant to the locations of all three epicenter considered in this research. Each epicenter resides within the central expanse of red, illustrating site class 'E,' in Figure 30. The strongest ground motions experienced near the epicenter will be reduced due to the presence of extremely soft soils. At greater distances, however; lesser ground motions will be amplified, in the north and west for example. This creates a larger region of moderate shaking, 0.1*g* to 0.3*g*, as seen in Figure 32.

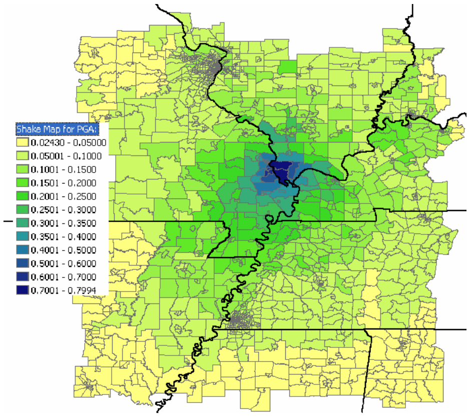


Figure 32: PGA Map for Improved Site Class

In addition to the soil class improvement procedure employing the regional site class map the FEMA baseline maps discussed earlier also incorporate site class parameters. The maps themselves were developed with this information and thus do not require updating or alterations to obtain regional ground motion values that reflect local site effects.

5.2.4 Liquefaction Susceptibility

A critical factor required to adequately represent the seismic hazard in the New Madrid Seismic Zone is regional liquefaction susceptibility. Surface built inventory such as highways and airport runways are only impacted by permanent ground deformation as a result of liquefaction or landsliding. There is extensive evidence of widespread paleoliquefaction events in the NMSZ. In addition, the soils layer developed by the CUSEC state geologists describes the Type F soils as liquefiable. A liquefaction proxy was developed by Doug Bausch at FEMA Region VIII to approximate the potential for permanent ground deformation. All susceptibility classifications are based on the aforementioned site class map for the NMSZ. Site classes are assigned a corresponding susceptibility level, assume shallow ground water, and are based on NEHRP liquefaction susceptibility levels (Bausch – Liquefaction Proxy, 2006), as seen in Table 17. These classifications are associated with site characteristics, such as soil composition and shear wave velocity and propagation.

Table 17: Liquefaction Susceptibility Classifications for NMSZ

Soil Type	Description	Liquefaction Susceptibility	HAZUS-MH Value
A	Hard Rock	NONE	0
B	Rock	NONE	0
C	Very Dense Soil & Soft Rock	LOW	1
D	Stiff Soils	HIGH	4
E	Soil Soils	VERY HIGH	5
F	Soils Requiring Site-Specific Evaluation	VERY HIGH	5

There is a critical need for regional geologists and seismologists to provide liquefaction susceptibility assignments within the New Madrid Seismic Zone. With the exception of the Type F soils described as liquefiable, as well as the presence of paleoliquefaction features, the rubric used to ascertain site class is nothing more than an estimation of behavior based on typical site class response to seismic activity. The liquefaction proxy (See Figure 16) needs to be replaced with a product that is better supported by geological mapping and data. Results generated from its use should only be considered approximate. Industry and government professionals warn that the use of this data may not reflect the actual response of the ground, in terms of liquefaction probability, and lateral spreading. However, it should be noted that permanent ground deformation in the NMSZ scenarios may be underestimated due to the lack of a landslide susceptibility layer.

A possible solution would be to use liquefaction susceptibility data based on experimental and field research. Information of this type, however; is severely lacking in the Central and Eastern U.S. Two local studies were commissioned by the USGS several years ago to investigate the liquefaction susceptibilities of two major urban centers in the New Madrid Seismic Zone; St. Louis, Missouri, and Memphis, Tennessee. While these studies present highly refined data based on field surveys, the area covered between the two is negligible on the regional level used in this research. Subsequent phases of the New Madrid catastrophic planning effort focusing on local assessments will employ these highly-refined liquefaction susceptibility maps. Due to the detailed nature of these maps it is likely that the damage and losses determined in these major urban areas will be greater than those determined for the same cities in the larger regional impact assessment. Additionally, Tsai et al. (2006) have investigated the affects of depth-dependent site factors in the Mississippi Embayment and the deep sediment deposits in the area. This information may aid in the determination of better liquefaction susceptibility evaluations, however; at the time the research discussed herein was completed the work on depth-dependent site factors was not available for use and thus not incorporated. As a result of these factors the FEMA-developed liquefaction susceptibility proxy remains the only source of information and is used by default, since it is deemed more crucial to include approximate data than to include none at all.

The baseline study used as a reference in this research developed a separate set of hazard maps for their study region in the New Madrid Seismic Zone, similar to those developed in this research. Maps sets (PGA, PGV, S_a 0.3 sec. and S_a 1.0 sec.) were created for a magnitude 7.7 earthquake on each of the three New Madrid Fault thrusts. In addition to non-zero ground motions at distances greater than 200 km, FEMA/USGS maps also account for soil amplification through the use of site class factors which are identical to the site class map used in this research. While standard HAZUS-MH CEUS Event attenuation functions and weighting factors are applied to the ground motions generated herein, FEMA and the USGS did not develop their baseline maps in accordance with the HAZUS-MH CEUS attenuation approaches; CEUS Event or CEUS Characteristic Event. Baseline shake maps were developed with a modified fault-rupture model similar to the format used by the USGS for national hazard map construction. Ruptures employed for fault thrusts are characterized by coordinates for depth-to-top, dip and down-dip-length of rupture instead of epicenters (or hypocenters) that apply to HAZUS-MH attenuations. It should be noted that FEMA ground motions are significantly higher than the hazard values determined in this research using CEUS Event weighted attenuations. This trend is evident when Figure 14 and Figure 32 are compared. Further comparison with baseline hazard levels is discussed in subsequent sections.

6 Earthquake Impact Assessment

6.1 Level I Analysis

A Level I analysis in HAZUS-MH is comprised of default inventory and fragilities in conjunction with internal hazard calculation. For this type of deterministic analysis the hazard definition only requires the user to specify the location of an epicenter and earthquake intensity. As discussed earlier all Level I analyses employ the CEUS Event consisting of the attenuation relations highlighted in the HAZUS-MH Methodology section. There is no consideration for soil amplification, liquefaction or various other parameters which modify ground shaking and damage values in a Level I analysis. With virtually no region-specific data the accuracy of this form of analysis is very low. Loss assessments completed with default data are used typically to provide a baseline for comparison against future analyses with improved hazard, inventory and fragility data. The Level I analysis detailed herein serves this purpose by providing initial estimations of damage and economic loss for the New Madrid Seismic Zone.

Adequate portrayal of the hazard present in the CEUS requires the implementation of three potential earthquake locations corresponding to the three proposed thrusts of the New Madrid Fault. As seen in Figure 21, there are three suggested locations each with three segments. Potential epicenters are positioned according to those illustrated in the aforementioned figure and Level I analyses run for each hazard scenario. A comparison is then completed for the determination of a worst-case scenario at the default level of analysis.

6.1.1 Northeast Epicenter

6.1.1.1 Ground Motion

Hazard is defined via the ground motion map generation procedure outlined in the previous Hazard Definition section. Shake maps for the northeast epicenter equate to ground motion results within HAZUS-MH since all attenuations are applied externally. Ground shaking results for the northeast epicenter are illustrated in Figure 33 - Figure 36.

Peak ground accelerations are most intense within 40 km of the epicenter, where PGA > 0.35*g*. Maximum accelerations, however; occur within the census tract where the epicenter is located and experience intensities of nearly 0.9*g*. Moderate shaking values between 0.05*g* and 0.35*g* cover a considerable portion of the region. Only extreme southern counties and several northwestern census tracts realize minimum PGA values less than 0.05*g*. The lack of site-specific soil conditions permits the concentric appearance of PGA and all other shaking response parameters.

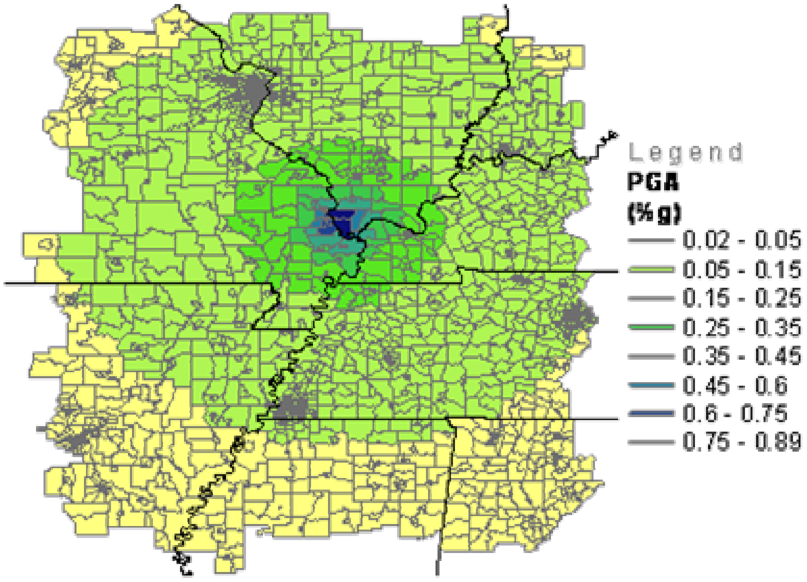


Figure 33: Peak Ground Acceleration (g) – NE Level I

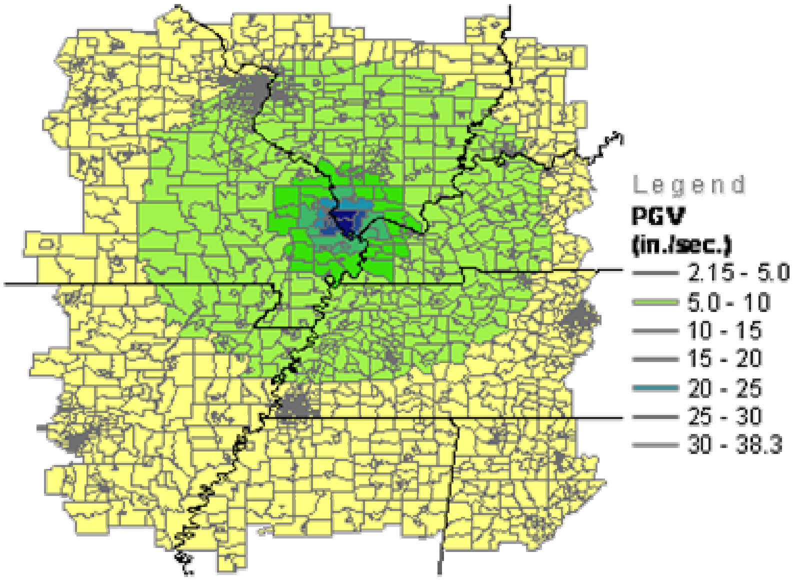


Figure 34: Peak Ground Velocity (in./sec.) – NE Level I

Similar trends are exhibited by the peak ground velocity and spectral acceleration responses. Tracts nearest the epicenter experience maximum shaking values while the majority of the region sees only moderate shaking, such as PGV where most of the region is assessed between 5 in./sec. and 15 in./sec. Spectral accelerations show significant shaking, greater than 0.5*g*, within 50 km of the epicenter for a period of 1.0 seconds. Short-period spectral accelerations are far greater than long-period spectral accelerations, with maximum values near 2.2*g*. Large spectral acceleration values generate more damage to structures which will be reflected in extensive and complete damage state probabilities.

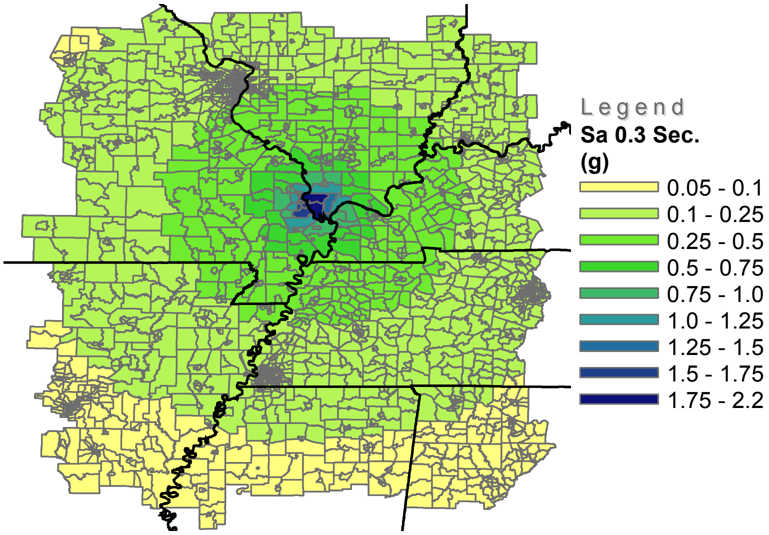


Figure 35: Sa 0.3 Sec. (g) – NE Level I

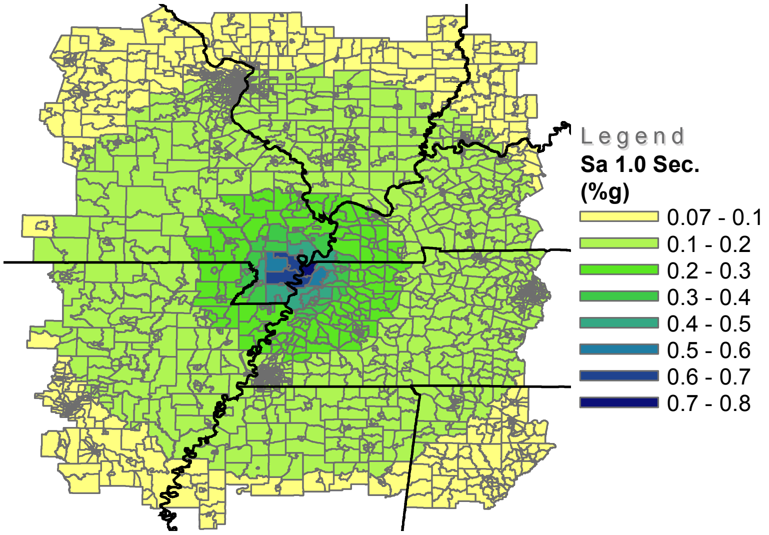


Figure 36: Sa 1.0 Sec. (g) – NE Level I

Resulting spectral displacement values show large displacements in the northern portion of the study region. Displacements greater than one-inch occur within 50km of the epicenter for short-period structures. Maximum displacement values greater than 4 four-inches near the epicenter are likely to cause severe damage to structures subjected to short-period excitation. Long-period structures are likely to experience even larger displacements, greater than five-inches, nearest the epicenter. The majority of the study region sees long-period spectral displacements greater than 0.75-inches (See Figure 37 & Figure 38), which is enough to damage most structures, as well as buried pipelines.

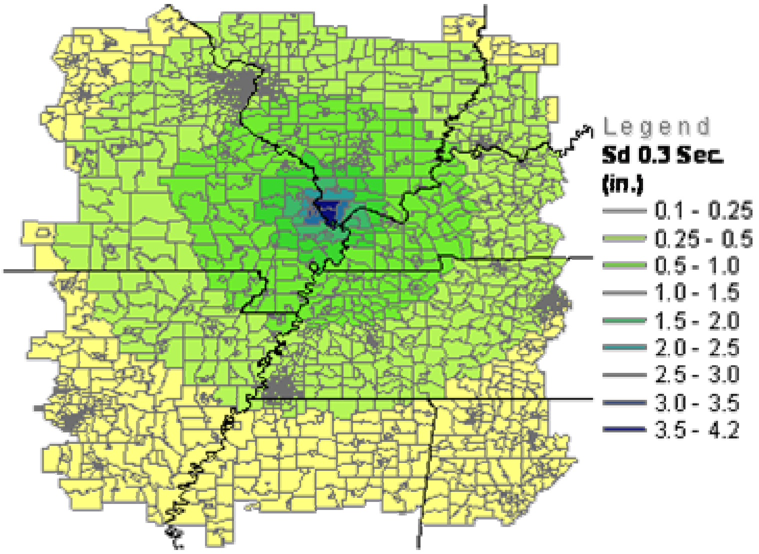


Figure 37: S_d 0.3 Sec. (in.) – NE Level I

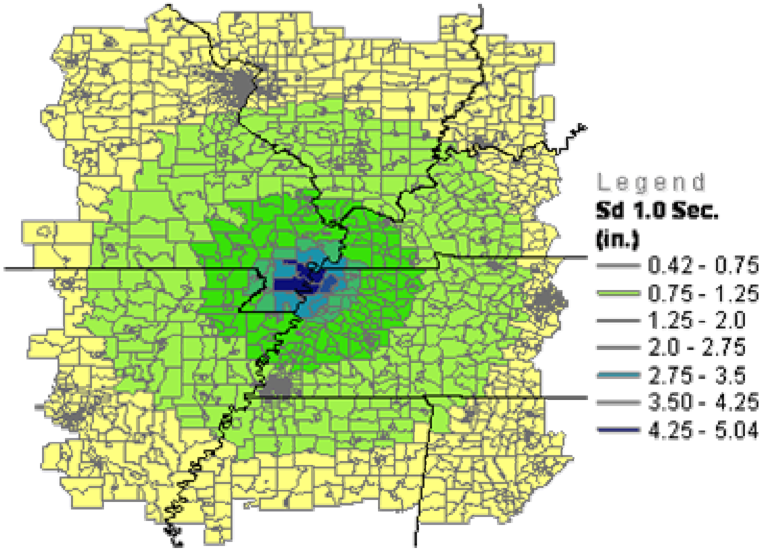


Figure 38: S_d 1.0 Sec. (in.) – NE Level I

6.1.1.2 General Building Stock

The general building stock encompasses all buildings constructed within the study region. These buildings are classified by building type and occupancy/use. Figure 39-Figure 42 illustrate the distributions of square footage and building count by both general occupancy and general building type. The predominant general building type is wood fame construction (light wood frame specific building type), with 72% of the buildings, or over 2.7 million buildings in the study region. This equates to nearly 5.1 billion square feet and 65% of the total square footage built with wood frame construction. Additional common specific building types include low-rise unreinforced masonry (URML) and mobile homes (MH) at 13.8% and 12.7% of the total building count, or 526,000 and 484,000 building, respectively. These building types also account for 17.5% and 6.7% of

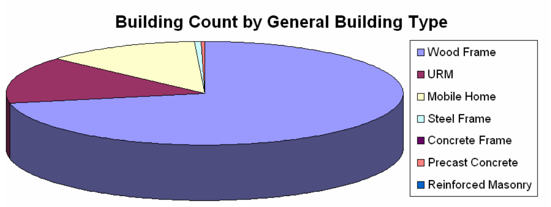


Figure 39: Building Count by General Building Type

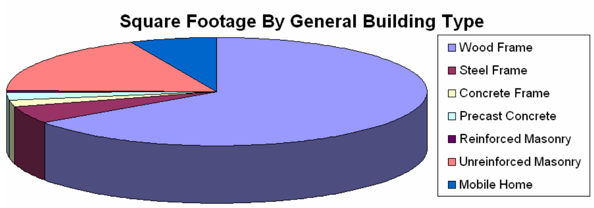


Figure 40: Square Footage by General Building Type

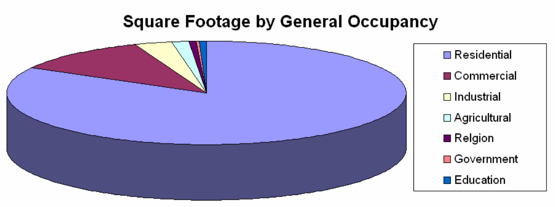


Figure 41: Square Footage by General Occupancy

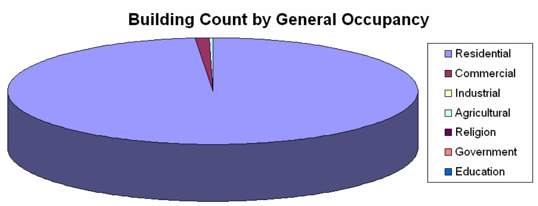


Figure 42: Building Count by General Occupancy

the total regional square footage with URML buildings covering 1.4 billion square feet and mobile homes comprising 0.5 billion square feet. Since these three building types comprise over 95% of the regional general building stock inventory analysis of regional damage focuses on these three building types.

The primary general occupancy class present in this study region in the residential class. Nearly 99% of the over 3.8 million buildings are residential, with 82.4% of those being single family homes and 12.7% being manufactured housing. Residential buildings equate to 82.5%, or 6.5 billion square feet of regional construction. Commercial building account for 11.7% of regional square footage, while the remaining 5% is divided between industrial, agricultural, religion, education and government buildings, in descending order of regional square footage. These building types, with the addition of commercial buildings comprise just over 1% of the total number of buildings, however. Due to this inventory distribution damage state assessments of all analyses will focus on residential and commercial buildings as they account for the majority of the general building stock inventory.

Building types in HAZUS-MH are classified by seismic design levels; high-, moderate-, low- and pre-code. The study region used in this research includes moderate-, and low- and pre-code classifications within the general building stock. Moderate-code building exists along the New Madrid Fault and low-code building comprise the remainder of the region, as classified in HAZUS-MH. This classification geography is represented in Figure 43. Pre-code buildings can be found throughout the region.

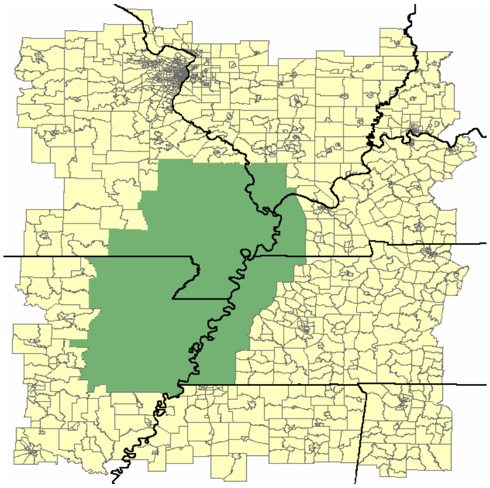


Figure 43: Moderate-Code Classification Boundary

Damage state probabilities for the primary building type, light food frames, indicate that the majority of these structures are unlikely to sustain structural damage. Figure 44 illustrates the probability that W1 structures experience no structural damage. The greatest probability, depicted in blue, shows the extent of building greater than 70% likely to undergo no structural damage, which encompasses the majority of the region. Figure 45 illustrates at least moderate damage probabilities, meaning the probability of experiencing moderate, extensive or complete structural damage. The only tracts with more than a 10% probability of experiencing at least moderate damage are within 50 km the epicenter.

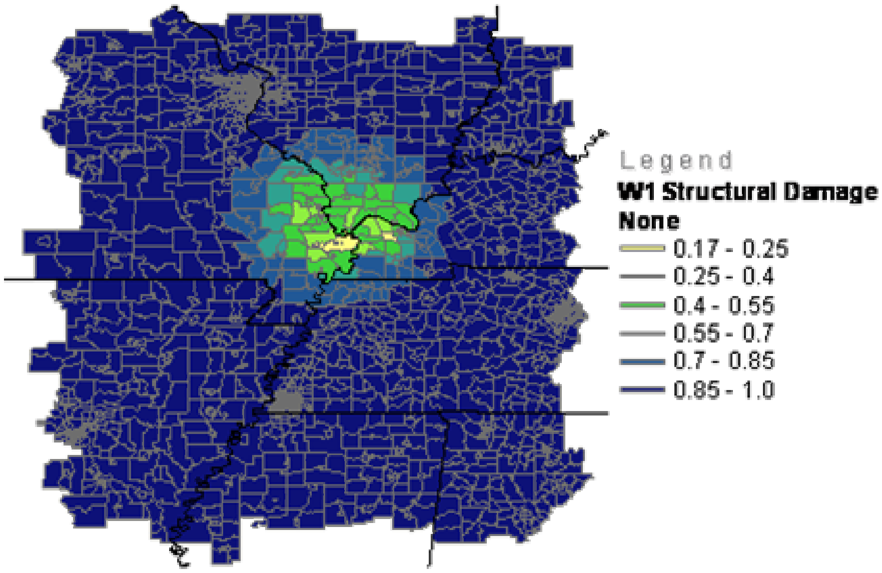


Figure 44: No Damage - W1 – NE Level I

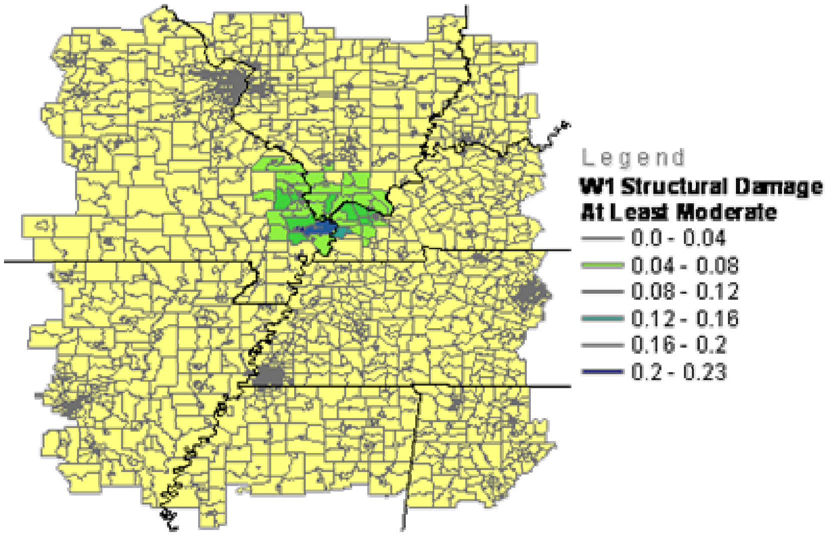


Figure 45: At Least Moderate Damage - W1 – NE Level I

Additional categories of damage include non-structural acceleration damage, which applies to interior partitions, mechanical equipment and electrical equipment. Non-structural drift damage affects building contents and is specified in yet another damage calculation. The probabilities of at least moderate damage for these two damage types are illustrated in Figure 46 & Figure 47. While structural damage is confined to a small region near the epicenter, non-structural damage of similar likelihoods (i.e. 10%, 20%, etc.) extend farther from the epicenter. Non-structural damage due to acceleration,

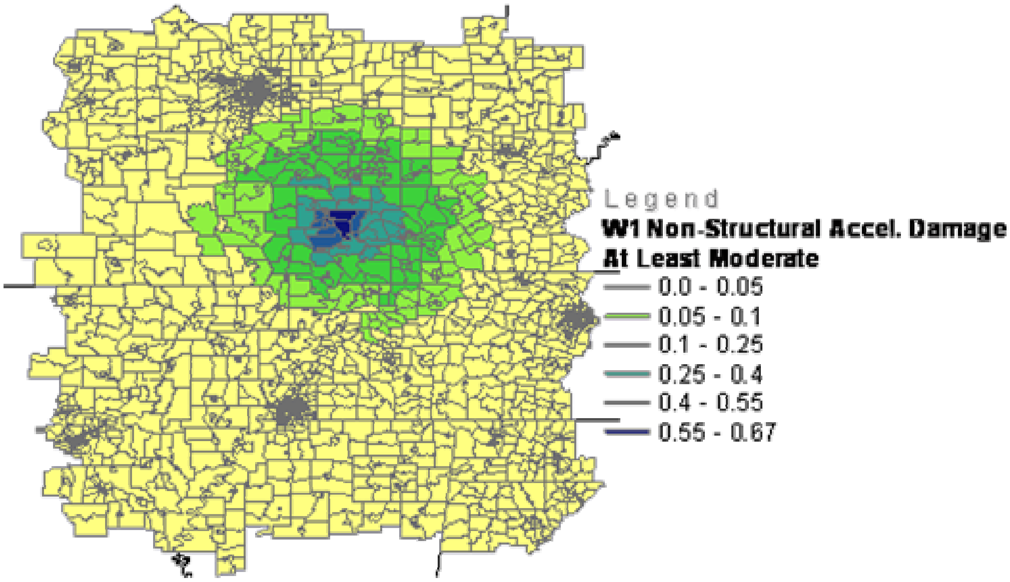


Figure 46: At Least Moderate Damage - Non-Structural Acceleration - W1 – NE Level I

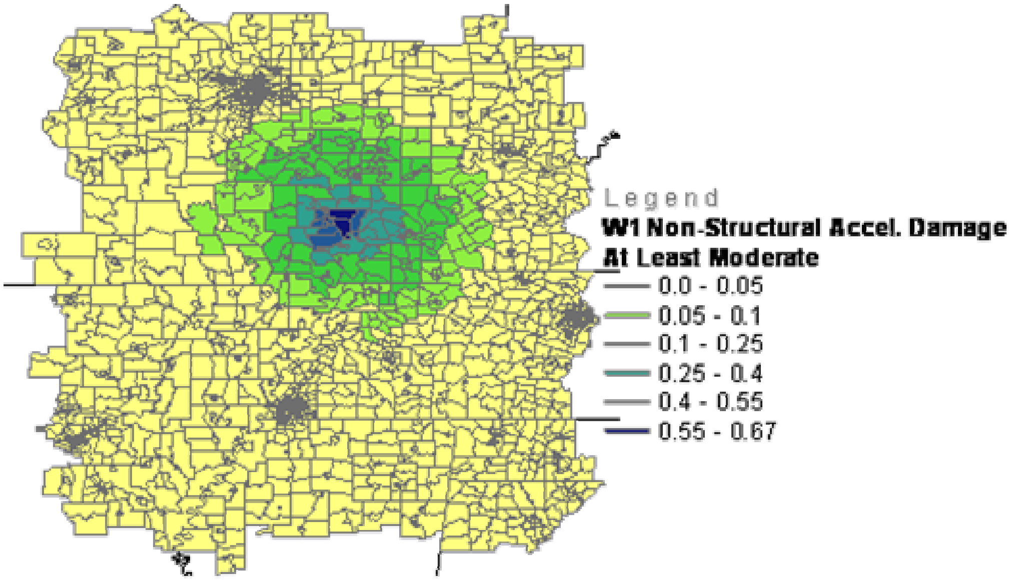


Figure 47: At Least Moderate Damage - Non-Structural Drift - W1 – NE Level I

in particular, is at least 25% probable up to a distance of 90 km from the epicenter. This form of damage is experienced roughly twice as far as structural damage of comparable likelihood. Non-structural drift damage covers roughly the same are as structural damage, though the probability of non-structural damage due to drift is much greater within that area. Damage probabilities are likely to be greater than 30% for at least moderate damage as oppose to greater than only 10% with strictly structural damage.

A second critical building type in the Central and Eastern U.S. is unreinforced masonry buildings. These structures are numerous as well as susceptible to damage which often lead to numerous deaths as was highlighted in the FEMA baseline study. Default damage state probabilities for the no structural damage case are illustrated in Figure 48. As with light wood frames the blue color indicates lower likelihoods of damage. For URMs greater than 65% probability of no structural damage exists at distances greater than 150 km from the epicenter, while structures within 75 km of the epicenter are almost guaranteed to experience damage. Probabilities of at least moderate structural damage appear to be the mirror image of the no structural damage case. Greater than 50% likelihood of exceeding this damage state exists up to 100 km from the epicenter, as seen in Figure 49.

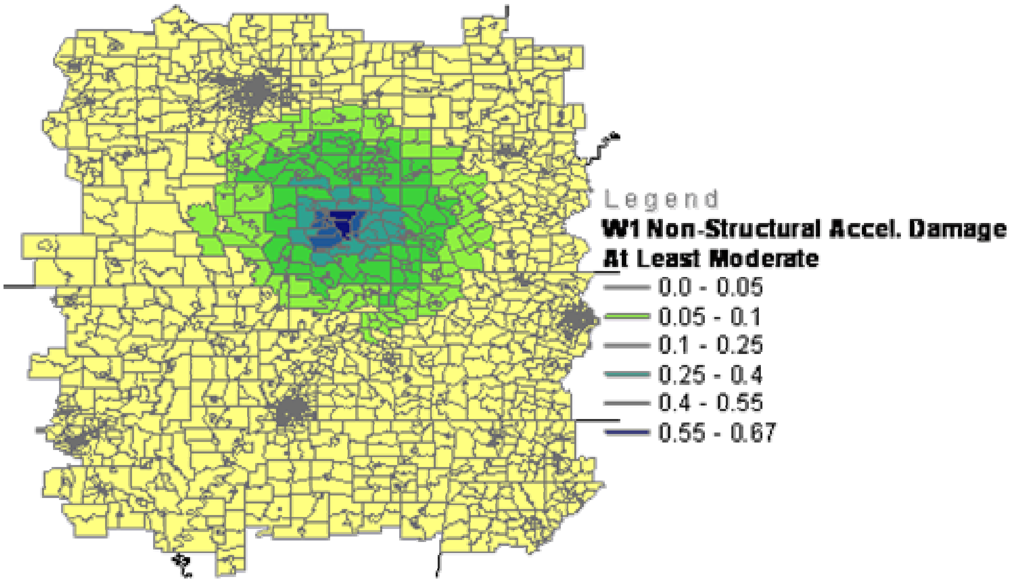


Figure 48: No Damage – URML – NE Level I

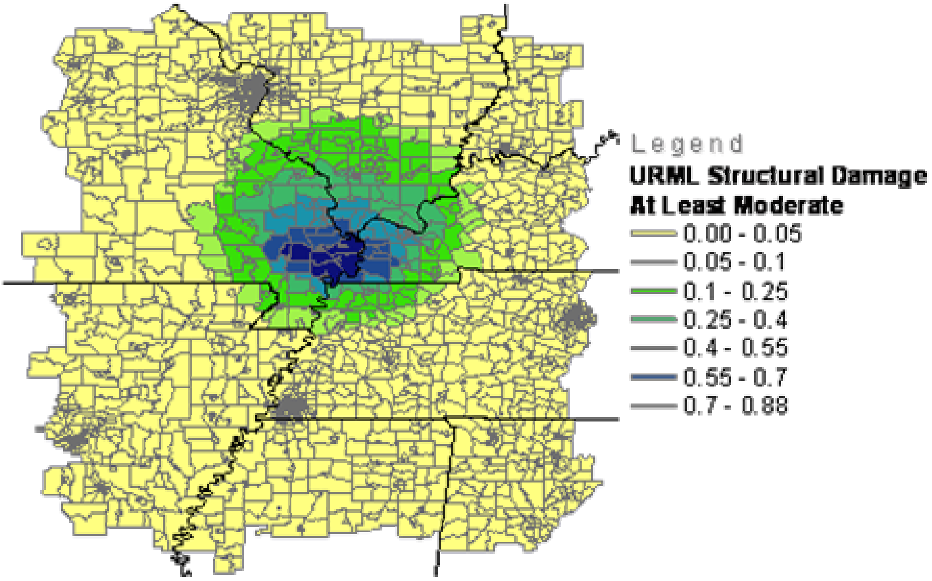


Figure 49: At Least Moderate Damage – URML – NE Level I

Non-structural damage patterns for URMs are similar to those of wood frame structures. As shown in Figure 50 & Figure 51, acceleration-controlled and drift-controlled damage are critical nearest the epicenter. While non-structural damage due to acceleration encounters lower probabilities as source-to-site distances increase, damage likelihoods greater than 10% extend noticeably farther from the epicenter than drift controlled damage, by approximately 50 km. Drift-sensitive damage probabilities for non-structural elements, however; exhibit much higher probabilities of damage as epicentral distances increase to nearly 90 km. Regardless of which variable damage is sensitive too, non-structural components in URMs are likely to experience damage nearest the epicenter like wood frame structures.

Mobile homes exhibit damage probability trends similar to those seen for wood frame and URM structures. Likelihoods of at least moderate damage extend slightly beyond those of the previous two structure types, however. As shown in Figure 52, structural damage probabilities greater than 10% reach farther than 200 km from the northeast epicenter, with likelihoods greater than 55% extending up to 100 km from the epicenter. Wider ranges of more severe damage states apply to extensive damage, while the extent of the area expected to see no damage decreases. Both forms of non-structural damage state probabilities follow trends represented by previous structure types, though with the greater source-to-site distance ranges illustrated for this particular structure type.

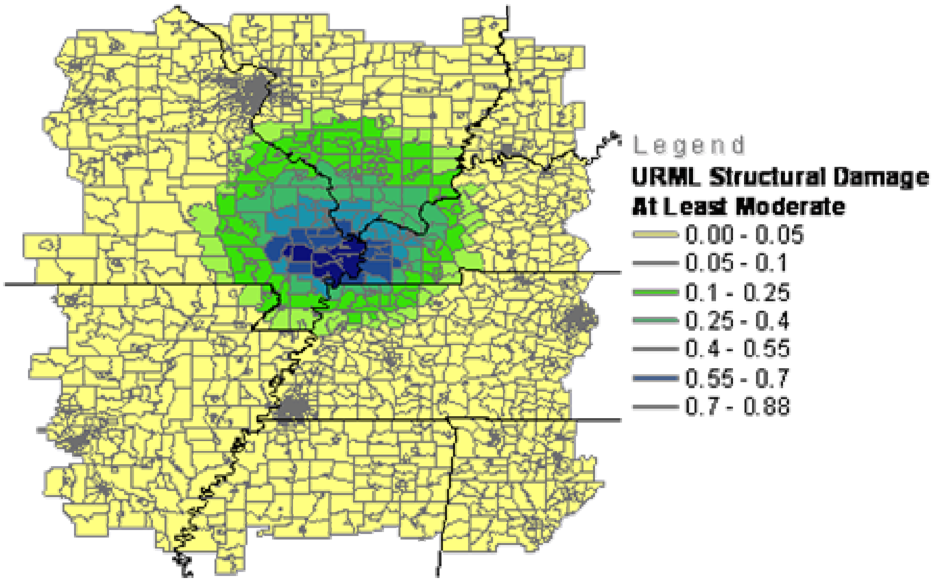


Figure 50: Non-Structural Acceleration – URML – NE Level I

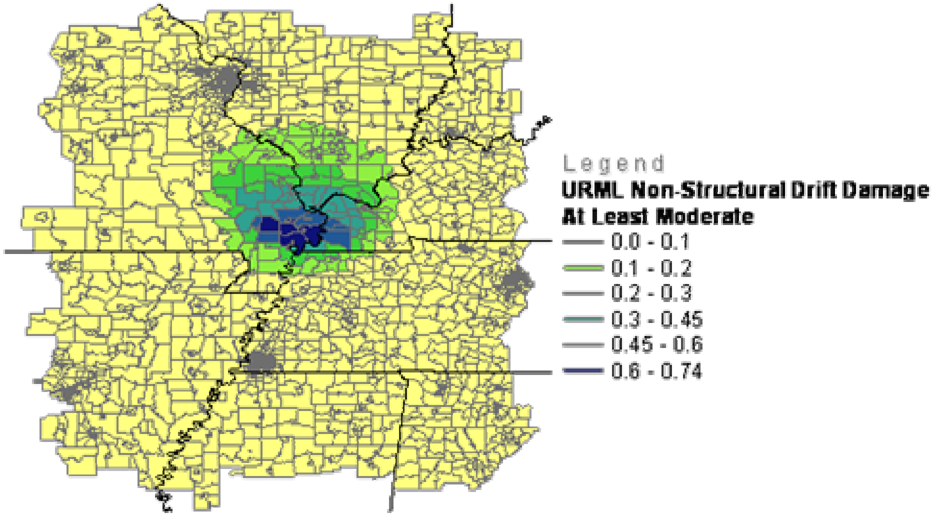


Figure 51: Non-Structural Drift – URML – NE Level I

A second method to determine damage to the general building stock is to consider the number of buildings damaged. One manner in which this may be accomplished is to focus on the three primary building types present in the study region; light frame wood construction, unreinforced masonry structures and mobile homes. Damage is quantified by seismic code level and damage state, then totaled for each building type, and finally a percentage of the total inventory in a particular damage state is determined. These values are outlined in Table 18. This table illustrates the performance of each building type, with light wood frames experiencing the least damage, percentage-wise, despite the total number of damaged wood frame structures being greater than the remaining two. Mobile homes suffer the greatest losses, with roughly 60% of this building type sustaining some form of damage. Over 20% of all unreinforced masonry buildings experience damage due to seismic activity, while 5% of those buildings that are damaged sustain extensive damage or total collapse.

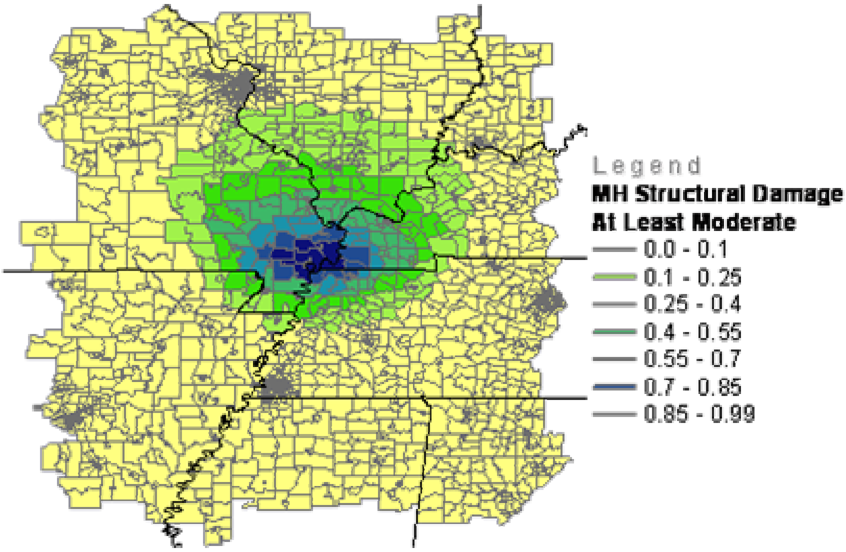


Figure 52: At Least Moderate Damage - Mobile Homes – NE Level I

Table 18: Damage State by Building Count – NE Level I

	Light Wood Frame				
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Buildings	439,548	31,811	15,471	1,877	142
Total Low Code Buildings	2,184,833	74,793	5,915	67	0
Total Buildings	**2624381**	**106604**	**21386**	**1944**	**142**
		Total Number of Building Type:			2754457
%Total Buildings	***95.278%***	***3.870%***	***0.776%***	***0.071%***	***0.005%***
	Unreinforced Masonry				
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Buildings	40,647	6,910	5,484	4,166	2,456
Total Low Code Buildings	156,420	16,321	5,154	823	58
Total Pre-Code Buildings	217,560	45,517	17,152	4,695	2,065
Total Buildings	**414627**	**68748**	**27790**	**9684**	**4579**
		Total Number of Building Type:			525428
%Total Buildings	***78.912%***	***13.084%***	***5.289%***	***1.843%***	***0.871%***
	Mobile Homes				
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Buildings	21,154	9,237	9,963	4,060	949
Total Low Code Buildings	139,743	19,340	10,764	977	2
Total Pre-Code Buildings	136,379	49,005	63,017	17,391	2,613
Total Buildings	**297276**	**77582**	**83744**	**22428**	**3564**
		Total Number of Building Type:			484594
%Total Buildings	***61.345%***	***16.010%***	***17.281%***	***4.628%***	***0.735%***

Damage to regional structures is further defined by a local damage state assessment. By defining damage on a state-wide basis it is clear how the location of an epicenter impacts the amount and type of damage local structures experience. A northeast epicenter event yields damage according to the statistics outlined in Table 19. While this table provides total damage estimates for the entire region, nearly 7% of building sustaining damage, or approximately 230,000 buildings, also details which areas experience the greatest amount of damage. It is clear that Illinois and Missouri incur that largest number of damaged buildings, which is representative of all building types, not just the three primary types discussed earlier. States farther from the epicenter; Mississippi, Alabama and Arkansas, realize fewer damaged buildings than the northern states. It is also relevant to note that damage severity as determined by building count is a function of the inventory in a state, meaning that states with fewer buildings are likely to incur fewer damaged buildings, however; if that state is the site of an earthquake damage will not be proportional to states farther away.

Table 19: Building Damage by State – NE Level I

	Low-Code					
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**	**Total**
Alabama	205,329	162	4	0	0	**205,496**
Arkansas	343,961	732	30	0	0	**344,724**
Illinois	284,040	37,610	10,142	1,163	50	**333,005**
Indiana	124,678	3,515	252	4	0	**128,450**
Kentucky	158,169	25,791	6,791	613	20	**191,385**
Mississippi	231,760	628	18	0	0	**232,406**
Missouri	636,668	29,047	3,571	174	5	**669,465**
Tennessee	503,772	13,947	1,704	43	0	**519,466**
Code Total	**2,488,378**	**111,432**	**22,514**	**1,998**	**75**	**2,624,396**
	Moderate-Code					
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**	**Total**
Alabama	0	0	0	0	0	**0**
Arkansas	137,487	6,944	932	17	0	**145,380**
Illinois	517	2,853	4,290	2,283	1,101	**11,045**
Indiana	0	0	0	0	0	**0**
Kentucky	3,917	3,539	1,956	564	52	**10,028**
Mississippi	0	0	0	0	0	**0**
Missouri	38,226	25,862	22,272	7,293	2,430	**96,083**
Tennessee	325,400	9,115	1,868	114	1	**336,498**
Code Total	**505,548**	**48,313**	**31,319**	**10,271**	**3,584**	**599,035**
Region Total	**2,993,926**	**159,746**	**53,833**	**12,268**	**3,658**	**3,223,431**
% Region Total	***92.880%***	***4.956%***	***1.670%***	***0.381%***	***0.113%***	

Finally, damage may be quantified by overall square footage based on building type. Table 20 displays square footage values defined by code level and damage state of the three primary building types in the CEUS. Of the nearly 4.9 billion square feet of light wood frame construction, only 6% sustain damage, while over 20% of unreinforced masonry buildings and 40% of mobile homes experience damage. As with building count damage estimates, approximately 0.8% of all light wood frames are damaged extensively or collapse, which is far less than the 2.5% and 5.5% seen with unreinforced masonry buildings and mobile homes, respectively.

Table 20: Building Damage by Square Footage – NE Level I

			Light Wood Frame		
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Square Footage	778,282,390	55,439,660	28,105,250	3,416,800	256,120
Total Low Code Square Footage	3,867,438,150	133,758,650	10,810,940	132,640	200
Total Square Footage	**4,645,720,540**	**189,198,310**	**38,916,190**	**3,549,440**	**256,320**
		Total Number of Square Footage Type:			4,877,640,800
%Total Square Footage	***95.245%***	***3.879%***	***0.798%***	***0.073%***	***0.005%***
			Unreinforced Masonry		
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Square Footage	116890200	17114140	12504240	9560220	5773920
Total Low Code Square Footage	365956540	36656260	11772100	1969820	149530
Total Pre-Code Square Footage	614201520	119070660	43899390	12376280	5249180
Total Square Footage	**1,097,048,260**	**172,841,060**	**68,175,730**	**23,906,320**	**11,172,630**
		Total Number of Square Footage Type:			1,373,144,000
%Total Square Footage	***79.893%***	***12.587%***	***4.965%***	***1.741%***	***0.814%***
			Mobile Homes		
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Square Footage	23137030	10174810	10989170	4469420	1036470
Total Low Code Square Footage	151968670	21120550	11768140	1091110	7750
Total Pre-Code Square Footage	148213050	53587960	68916210	18993670	2894800
Total Square Footage	**323,318,750**	**84,883,320**	**91,673,520**	**24,554,200**	**3,939,020**
		Total Number of Square Footage Type:			528,368,810
%Total Square Footage	***61.192%***	***16.065%***	***17.350%***	***4.647%***	***0.746%***

Damage estimates categorized by occupancy permit determinations of use groups sustaining the greatest losses. Table 21 delineates loss by general occupancy and state. This data highlights the extensive damage incurred by residential buildings. Over 95% damage in each damage state is incurred by single family homes or other residential buildings. Commercial structures also exhibit significant damage with approximately 15% of all commercial buildings experiencing at least moderate damage.

Table 21: Building Damage by General Occupancy - NE Level I

	None		**Slight**		**Moderate**		**Extensive**		**Complete**	
	Count	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**
Agriculture	1,435	0.04%	433	0.17%	281	0.20%	51	0.14%	6	0.07%
Commercial	28,716	0.85%	4,363	1.69%	2,722	1.98%	782	2.20%	199	2.33%
Education	242	0.01%	31	0.01%	18	0.01%	4	0.01%	2	0.02%
Government	1,381	0.04%	187	0.07%	126	0.09%	31	0.09%	10	0.12%
Industrial	4,749	0.14%	680	0.26%	532	0.39%	135	0.38%	24	0.28%
Other Residential	419,874	12.46%	85,817	33.17%	86,455	62.73%	23,136	65.03%	3,829	44.78%
Religion	2,234	0.07%	252	0.10%	149	0.11%	49	0.14%	14	0.16%
Single Family	2,910,763	86.39%	166,969	64.53%	47,534	34.49%	11,387	32.01%	4,467	52.24%
TOTAL	**3,369,394**		**258,732**		**137,817**		**35,575**		**8,551**	

6.1.1.3 Essential Facilities

The general building stock provides comprehensive coverage of all buildings within a study region. Certain types of buildings, however; are critical to emergency response efforts and community safety thus these buildings are assessed separate from general buildings. These buildings are classified as essential facilities and include emergency care facilities (hospitals), police and fire stations, and schools. All essential facilities are assigned seismic code levels, similarly to the general buildings stock, though with point-wise structure definition the affect of code level is evident. Figure 53 expresses the probability of at least moderate damage to hospitals, and it is clear that the highest damage probabilities lie in the north-central portion of the region.

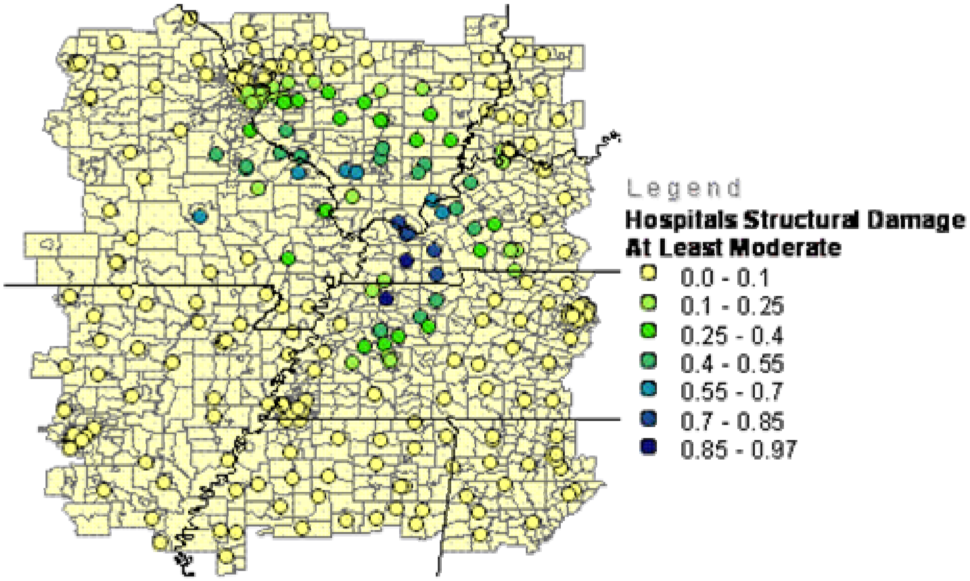


Figure 53: At Least Moderate Damage – Hospitals – NE Level I

When considering damage state as a function of ground acceleration, notice that hospitals designated pre-code and moderate-code experience significantly different damage state probabilities despite being exposed to the same level of ground shaking. This variation is due to the seismic code level assessed to each building. As was the case with the general building stock, structures along the New Madrid Fault are assessed moderate-code level seismic design, while all other areas, in particular the northeastern portion of this study region, are assessed a pre-code seismic design level. Many hospitals displayed in dark in Figure 53 are precast concrete construction and at least 10% likely to experience moderate damage. This means visible cracks, significant crack width and propagation up to collapse of these buildings. Figure 54 further delineates the likelihood of complete damage to hospitals. Even with pre-code specifications only two of 308 hospitals are more than 2.5% likely to collapse, indicating that even those buildings closest to the epicenter are not likely to collapse.

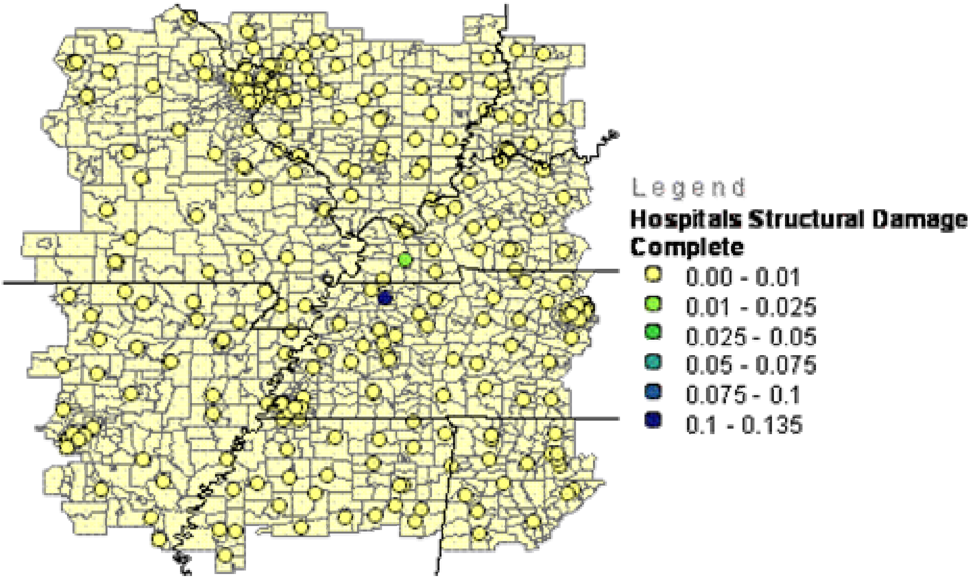


Figure 54: Complete Damage – Hospitals – NE Level I

Police station damage trends are similar to those seen in hospital damage. Only structures within 30 km of the epicenter are more than 10% likely to collapse. This equates 28 of the 1,207 total police stations in the study region. Structures nearest the epicenter are more than 50% to collapse, though this is directly related to the severe shaking occurring within kilometers of the epicenter (See Table 22).

Table 22: Essential Facilities Damage - NE Level I

	No. of Facilities		
Classification	Total	Moderate Damage >50%	Complete Damage >50%
Hospitals	308	39	0
Schools	4,695	287	27
EOCs	92	8	1
Police Stations	1,207	92	9
Fire Stations	1,465	122	6

Seismic code trends that apply to hospitals extend to police and fire stations as well. Both fire and police stations are specified as unreinforced masonry buildings, where structures near the NM Fault are designated moderate-code and the remainder of buildings classified as pre-code. Damage state probability distributions as well as the probabilities associated with damage states at specified source-to-site distances for police and fire stations are quite similar to those exhibited by hospitals. This trend is illustrated in Figure 55. The only variation to be noted is slight and results in a minimal increase in damage state probabilities for fire and police stations due to the structure type (UMRL) as opposed to the precast concrete structure classification of most hospitals. Schools are also assigned unreinforced masonry building types and thus show damage states distributions like those appearing in Figure 55 for fire stations.

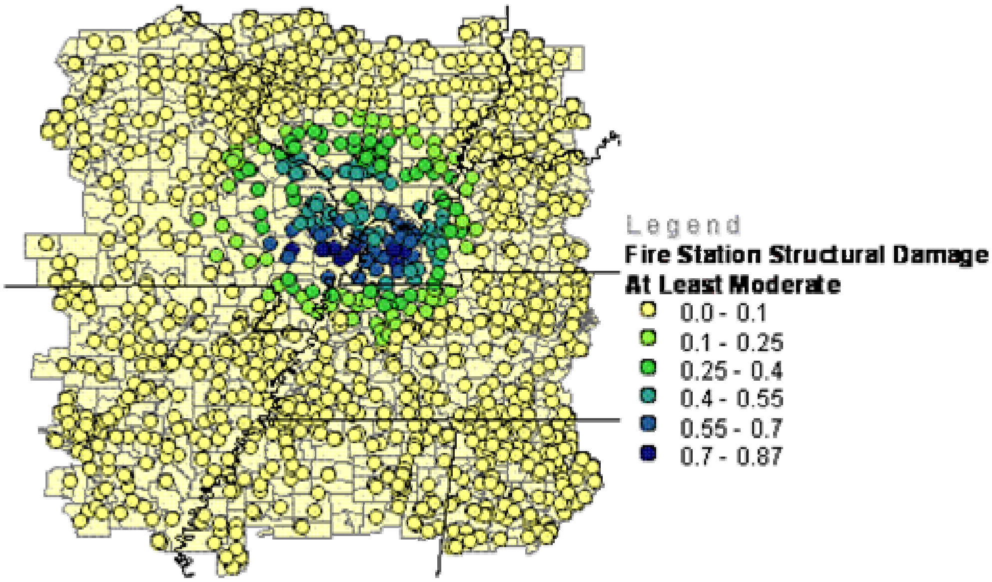


Figure 55: At Least Moderate Damage - Fire Stations – NE Level I

Essential facilities are also assigned functionalities to determine how long each facility will be non-operational in the aftermath of an earthquake. HAZUS-MH employs a baseline functionality level of 50% operational and thus is the functionality level considered acceptable in this research. This level can be adjusted by the user to reflect the required operational capabilities of a specific area. Functionalities of all essential facilities are enumerated in Table 23. Hospitals and fire stations present the lowest functionality ratings just one day after an earthquake, with 80.8% and 82.4% of the total facility type inventory operational, respectively. Schools are the most functional by far,

Table 23: Essential Facilities Functionalities – NE Level I

	Hospitals		Fire Stations		Police Stations		Schools	
	308 Total Strucutres		1465 Total Strucutres		1207 Total Strucutres		4695 Total Strucutres	
	No. Functional	**% of Total Functional**	**No. Functional**	**% of Total Functional**	**No. Functional**	**% of Total Functional**	**No. Functional**	**% of Total Functional**
Day 1	249	80.84%	1222	83.41%	1026	85.00%	4167	88.75%
Day 3	249	80.84%	1225	83.62%	1031	85.42%	4180	89.03%
Day 7	283	91.88%	1398	95.43%	1157	95.86%	4541	96.72%
Day 14	284	92.21%	1398	95.43%	1157	95.86%	4541	96.72%
Day 30	307	99.68%	1465	100.00%	1207	100.00%	4695	100.00%
Day 90	308	100.00%	1465	100.00%	1207	100.00%	4695	100.00%

as 85% of all schools are functional the day after an earthquake. It is not until a month after an earthquake that all essential facilities exhibit greater than 95% of all buildings functioning properly. Further illustration of essential facilities functionality is provided in Figure 56 where school functionality at 14 days post-earthquake is represented. It is evident that most schools in the study region are functioning, except for those within 75 km of the epicenter. With the addition of two more weeks post-earthquake only the schools in the immediate vicinity of the epicenter are non-operational, which is due to extensive damage and collapse from severe shaking. Again, it is critical to consider seismic code level, as these building sustain more damage and thus recover slower and remain non-operational longer than structures designed to more stringent seismic code levels.

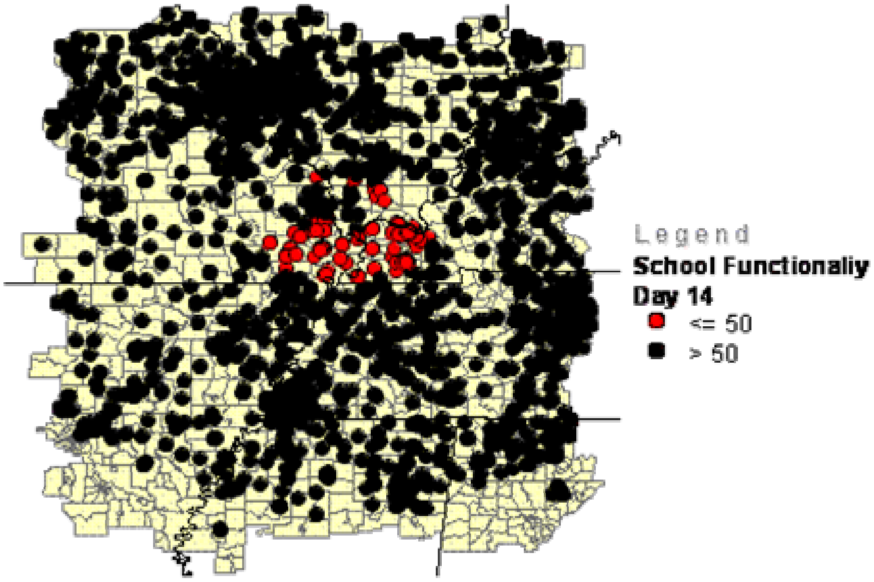


Figure 56: Schools Functionality at 14 Days – NE Level I

6.1.1.4 Transportation Systems

The transportation system is one of the most densely populated inventory categories in HAZUS-MH. It covers numerous modes of transportation including road, rail, waterways and air transport. Due to the massive amount of data provided for transportation system components this research will focus on highways, highway bridges, rail lines, railway bridges and airport damage and functionalities. There are over 30,000 highway bridges in this CEUS study region creating illegible damage maps, thus all damage state probabilities are reported via single quantities as oppose to maps. Of the 30,314 bridges of varying structural types only 2,647 bridges are more than 10% likely to suffer at least moderate damage. Occurrences of at least moderate damage are defined by 50% or greater probability of reaching a damage state, thus reducing the number of at least moderately damaged bridges to only 350, or 1.5% of all bridges. Only 41 bridges are more than 50% likely to collapse which can be attributed to there source-to-site distance being less than 30 km. With so few bridges likely to sustain damage this indicates that the majority of regional bridges are not likely to sustain more than slight damage, if any. Especially when HAZUS-MH estimates indicate that over 27,500 bridges, or 91%, are more than 80% likely to sustain no damage (See Table 24).

Table 24: Transportation Damage by Component - NE Level I

	Region Total	At Least Moderate Damage	Complete Damage
Highway Bridges	30,314	371	7
Railway Bridges	425	0	0
Railway Facilities	393	20	0
Bus Facilities	84	1	0
Ferry Facilities	5	5	5
Port Facilities	691	17	0
Airport Facilities	637	6	0

Bridges, like essential facilities, are classified operational when they are at least 50% functional. Based on this assumption the bridge recovery timeline is shown in Table 25. HAZUS-MH functionality predictions show that nearly 99% of all highway bridges are functional only one day after an earthquake. Functionality does not reach 100% within 90 days post-earthquake, and this is attributed to extensive bridge damage or collapse. Further estimates of highway bridge damage indicate that the value of this damage is more than $216 million dollars. Estimates of highway segment damage and loss are null in this analysis due to the lack of liquefaction information to estimate permanent ground deformations which are the critical factor for determining highway segment losses.

Table 25: Highway Bridge Functionality – NE Level I

Highway Bridge Fuctionality

Time	No. Functional	% Total Functional
Day 1	29957	98.82%
Day 3	30085	99.24%
Day 7	30119	99.36%
Day 14	30124	99.37%
Day 30	30158	99.49%
Day 90	30254	99.80%

Railway systems comprise 425 bridges and vast network of track throughout the CEUS. Track damage and loss are not calculated due to lack of liquefaction susceptibility information, however; railway bridge damage is determined. Only seven bridges are more than 10% likely to experience at least slight damage. These low probabilities of damage elicit damage estimates for railway bridges at $110,000.

Damage to airport facilities is illustrated in Figure 57. There are 36 airports more than 10% likely to meet or exceed the moderate damage state, while less than ten airports are more than 50% likely to exceed that same damage state. Only three airports in southern Illinois are more than 10% likely to experience collapse, indicating that nearly all airport facilities should remain standing following an earthquake. Airport facility related loss estimates are more than $156 million dollars for a seismic event on the northeast extension of the New Madrid Fault.

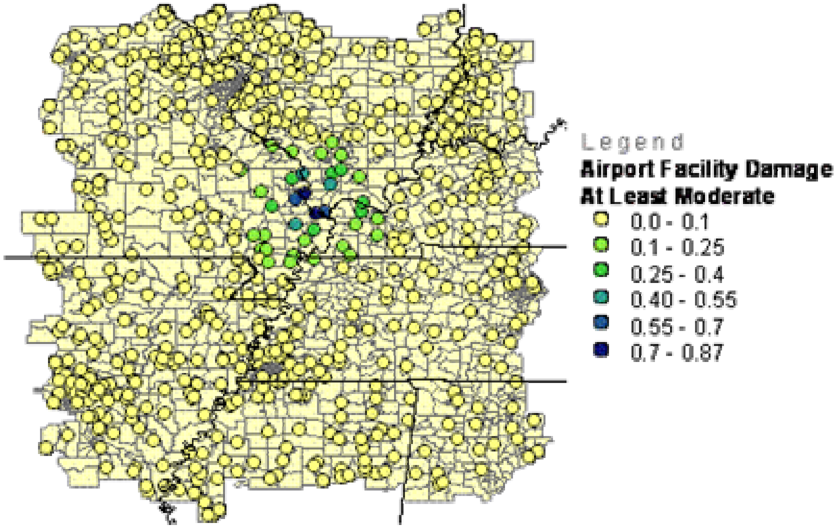


Figure 57: Airport Facilities - At Least Moderate Damage – NE Level I

6.1.1.5 Utility Systems

Default analyses of utility systems are governed primarily by the performance of utility facilities. HAZUS-MH inventory does not include pipeline information for any utility system, thus all estimates of pipeline damage are based on assumptions for pipeline distribution systems as previously discussed in the HAZUS-MH Methodology section. Damage to facilities, however; is determined for moderate damage or more severe and is pictured in Figure 58. The distribution of damage state probabilities, decreasing in concentric circles emanating from the epicenter, mimics damage trends seen in various other inventory groups. Distributions are similar for all other types of utility system facilities and thus are not illustrated here.

Damage estimates for pipelines are applicable for potable water, waste water and natural gas only. There are no assumptions made within HAZUS-MH for the distribution of oil pipelines which results in the null values shown in all fields under ‘Oil’ in Table 26. Potable water lines incur the greatest number of leaks and breaks, while natural gas lines exhibit the highest leak rate, 0.11 leaks/km, as oppose to 0.05 leaks/km and 0.07 leaks/km for potable water and waste water, respectively. Natural gas lines also have the greatest break rate at 0.028 breaks/km. Potable water and waste water lines show break rates one-third and two-thirds those of natural gas lines, respectively. These rates indicate that natural gas lines are more sensitive to ground shaking than water distribution lines.

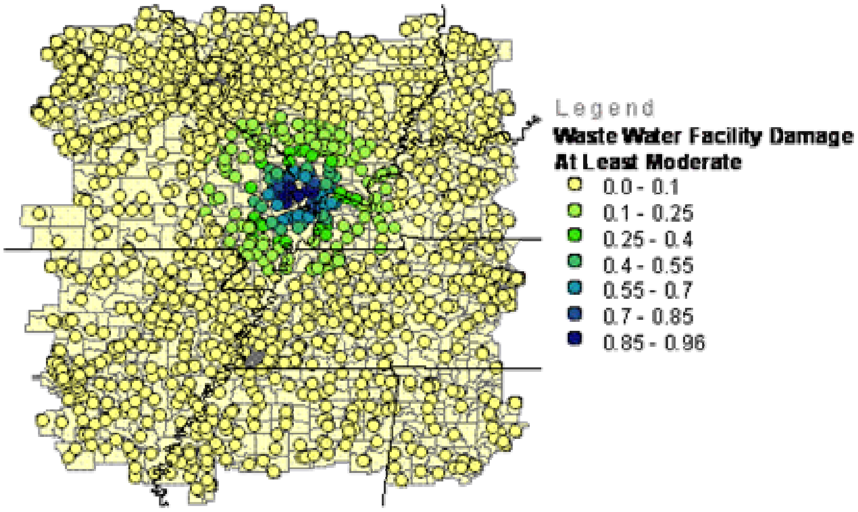


Figure 58: Waste Water Facilities - At Least Moderate Damage – NE Level I

Table 26: Pipeline Damage – NE Level I

	Total Pipeline Length (kms)	Number of Leaks	Number of Breaks
Potable Water	500,560	26,241	6,560
Waste Water	300,336	20,754	5,188
Natural Gas	200,224	22,185	5,546
Oil	0	0	0

Table 27: Utility System Component Damage - NE Level I

	Region Total	**At Least Moderate Damage**	**Complete Damage**
Potable Water	249	7	0
Waste Water	1,646	22	0
Natural Gas	114	0	0
Oil	49	0	0
Electric Power	158	2	0
Communications	940	11	0

Utility systems functionality is yet another critical parameters, particularly when post-earthquake service is required. Without functioning utilities even customers with inhabitable structures may not be able to stay due to a lack of utility services. Table 28 shows the functionality of each type of utility facility at various post-earthquake intervals. Waste water facilities appear to be most affected with only 1,548 treatment plants, or

94% of all facilities, operational the day after and earthquake (See Table 27). Natural gas and oil facilities do not have facilities located within 50 km of the epicenter and as a result these buildings remain almost entirely functional immediately after an earthquake. Electric and potable water functional losses lead to service disruptions which are quantified in Table 29. Losses of potable water outnumber electricity losses within the first week post-earthquake. Nearly 1.5% of customers are without potable water the day after an earthquake, though that number is reduced to less than 1% within the first three days. All customers are expected to regain potable water service after one month. Electricity does not recover as quickly as water service. Even after a month nearly 2,000 customers are still without power, and 60 still without power after three months.

Table 28: Utility System Functionalities – NE Level I

	Utility Facilities Functionality						
	Day 1	**Day 3**	**Day 7**	**Day 14**	**Day 30**	**Day 90**	**Total**
Potable Water	238	249	249	249	249	249	**249**
Waste Water	1548	1617	1637	1640	1640	1646	**1646**
Natural Gas	111	114	114	114	114	114	**114**
Oil Systems	49	49	49	49	49	49	**49**
Electric Power	151	156	158	158	158	158	**158**
Communication	934	940	940	940	940	940	**940**

Table 29: Electric and Potable Water Service Disruptions – NE Level I

		No. of Households without Service				
	Total No. Households	Day 1	Day 3	Day 7	Day 30	Day 90
Potable Water	4,236,197	57,022	38,691	24,465	0	0
Electric Power		46,712	28,436	10,912	1,951	60

Finally, structural damage to utility facilities results in repairs and reconstruction, all of which contribute to the economic impact of utility system losses in the study region. The economic value of facility losses are outlined in Table 30. Of the nearly $3.5 billion in utility system losses the greatest amount, 74% is incurred by waste water facilities. This is a result of the large number of facilities in the CEUS study region. Another 10.4% is attributed to electric systems damage and 6.8% related to potable water facilities. The remaining utilities do not represent a significant portion of the utility facilities inventory and thus do not generate significant loss value in comparison to major inventory categories.

Table 30: Utility System Losses – NE Level I

Utility System	Loss	% Total
Potable Water Facility	$234,760,000	6.75%
Potable Water Lines	$118,080,000	3.40%
Waste Water Facility	$2,563,630,000	73.73%
Waste Water Lines	$93,390,000	2.69%
Oil Facilities	$40,000	0.00%
Nautral Gas Facilities	$2,140,000	0.06%
Natural Gas Lines	$99,830,000	2.87%
Electric Systems	$363,150,000	10.44%
Communication	$1,900,000	0.05%
Total	**$3,476,920,000**	

6.1.1.6 Induced Damage

Damage to buildings and utility systems, in particular natural gas and oil systems leads to induced damage such as fires following the initial earthquake. Fire following earthquake is quantified in several ways, the first of which is the number of expected ignitions due to a given earthquake. This model is based on work completed for highly urban areas which is not representative of the region investigated herein (Hamada, 1975). In addition, the model is simplified to calculate fire ignitions, burned area and damage from fire based on building density and peak ground acceleration . Since this model is less complex than other damage and loss models in HAZUS-MH (such as building damage models) the fire following earthquake results should be considered approximate. With that in mind, HAZUS-MH predicts 50 ignitions across the entire study region. These fires are expected to displace 74 people and burn 0.40 square miles. These values equate to less than 0.5% of total regional population and surface area. Damage resulting from all fires is predicted to affect four million dollars of infrastructure value. Ignitions and induced damage does not necessarily occur nearest the epicenter as is common with various buildings, bridges and utility system facilities. Areas damaged by fire are located as shown in Figure 59. Damaged building value is located over 50 km from the epicenter, which is due to the fire following model employed in HAZUS-MH. Ignitions, and thus damaged value, is based on PGA and various other values including pipeline breaks and story drift in buildings. This generally equates to ignitions in more populated areas where utilities are buildings are more numerous.

Fires are defined further by the water demand required to extinguish them. The amount of water needed put out fires is shown in Figure 60. As with the exposed value, fire demand, or water required in gallons per minute (gpm), is randomly positioned as well. Census tracts near the epicenter require water to extinguish fires, though some of the greatest demands occur in outlying census tracts such as two in central Missouri and one it western Tennessee.

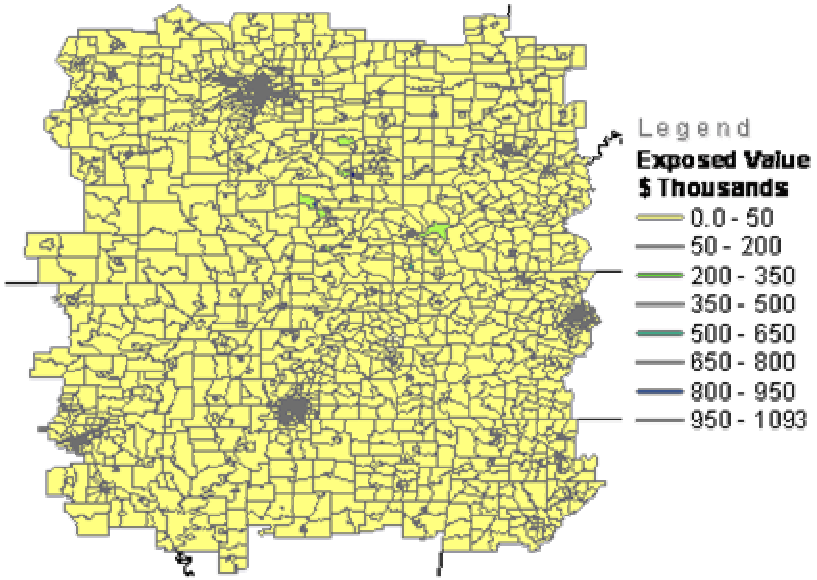


Figure 59: Fire Following EQ - Exposed Value ($) – NE Level I

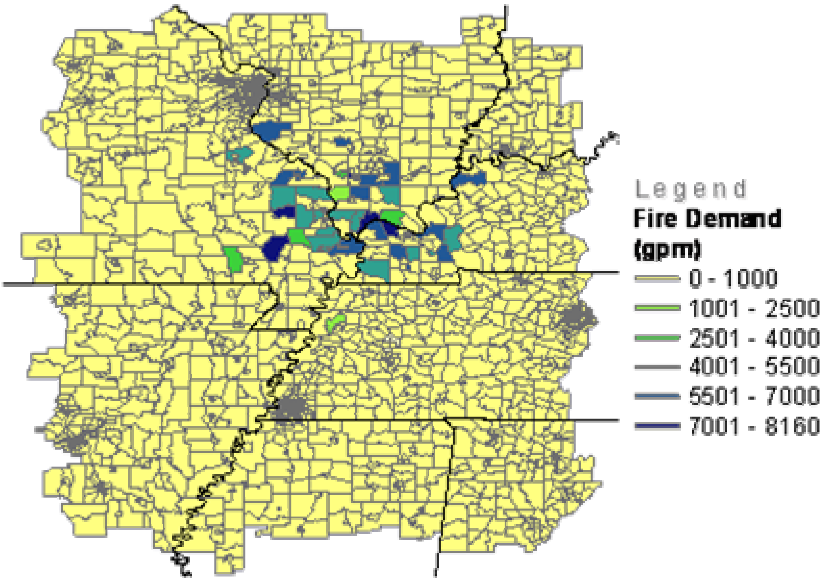


Figure 60: Fire Demand (gpm) – NE Level I

Damage to infrastructure components across the entire region generates debris which must be removed prior to and in conjunction with repair and recovery efforts. HAZUS-MH divides debris into two categories, brick/wood and steel/concrete. The earthquake presented in this scenario generates five million tons of debris, which is distributed according to Figure 61. Logically, debris generation patterns mimics building loss patterns since debris is created from damage to infrastructure components. Brick and wood comprises 53% of the debris generated with the remaining 2.35 million tons of debris is attributed to steel and concrete. Debris removal utilizes trucks with a capacity of 25 tons each, thus requiring roughly 200,000 truckloads to completely remove the debris generated from this earthquake.

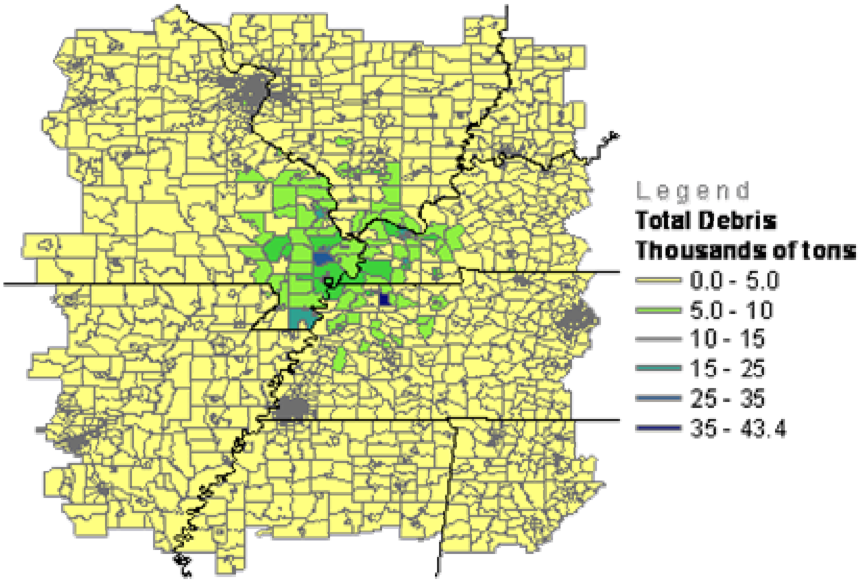


Figure 61: Total Debris Generation (thousands of tons) – NE Level I

Damage to structures, loss of utility services and induced damage all contribute to the number of uninhabitable structures as well as temporary and short-term shelter requirements region-wide. From a regional population of 10.9 million people 2,758 people are expected to seek temporary public shelter. In addition 9,924 households are anticipated to be displaced. Since supplementary housing needs are due to uninhabitable structures caused by severe structural and utility damage it is intuitive that displaced persons trends follow the building damage trends illustrated in previous discussions of damage by building type.

6.1.1.7 Social and Economic Losses

HAZUS-MH also determined amounts of injuries and deaths related to a given hazard, all of which are termed 'casualties' and they are divided into four severity categories. Please reference the HAZUS-MH Technical Manual for these classifications. Casualties caused by damage from an earthquake are calculated for three times throughout the day; 2AM, 2PM and 5PM to represent times where people are at home, at work and commuting. These injuries and deaths are further categorized by general occupancy type. The worst case scenario occurs at 2 PM, with 6,723 casualties of varying levels. The fewest casualties occur at 5 PM, with only 6,557 casualties. Table 31 illustrates the distribution of casualties for the worst case scenario. The majority of casualties are minor injuries, while approximately 6% are severe injuries or casualties. Commercial buildings are also cited as the occupancy class experiencing the greatest number of casualties, with approximately half of all causalities at each severity level occurring in commercial structures.

Table 31: Casualties - 2 PM – NE Level I

	Level 1	Level 2	Level 3	Level 4
Commercial	2,914	616	77	149
Commuting	3	3	6	1
Educational	724	164	23	44
Hotels	10	2	0	1
Industrial	452	94	11	22
Other-Residential	439	81	7	14
Single Family	648	152	22	41
TOTAL	**5,190**	**1,112**	**146**	**272**

Table 32: Shelter Requirements - NE Level I

	Displaced Households	Temporary Housing
Alabama	0	0
Arkansas	3	1
Illinois	300	91
Indiana	5	1
Kentucky	312	90
Mississippi	0	0
Missouri	768	219
Tennessee	62	18
Total	***1,450***	***420***

Shelter requirements for this scenario are displayed in Table 32. A total of 420 temporary shelters are required to house displaced residents. Most of these temporary shelters, 95%, are needed in Illinois, Kentucky and Missouri, with over half required in Missouri alone.

With all direct damage, induced damage, shelter needs and casualties computed the final step in risk assessment is to determine the economic losses associated with the hazard applied to the study region. Losses are divided into direct and indirect economic losses. Direct economic losses are further categorized by infrastructure system; buildings, transportation and utilities. The first of these, direct losses due to building damage is by state displayed in Table 33 in thousands of dollars. This information shows that non-structural damage causes the greatest overall losses at nearly 50% of all building related losses. The state of Missouri experiences the largest economic loss of $4 billion of the total $8.5 billion for buildings. Loss ratio is also a critical factor in HAZUS-MH risk assessment. Loss ratios greater than ten indicate significant economic losses as compared to the value of inventory in a given area. Illinois, Kentucky and Missouri show the greatest loss ratios though these are much less than ten.

Building losses are also classified by occupancy type. These losses are also broken down by capital and income losses as was the previous table. Economic losses are displayed in millions of dollars. Capital stock losses are greatest for residential buildings, which is comprised of single family homes and other residential buildings. Approximately half of all capital losses are attributed to residential buildings with another one-third incurred by commercial buildings (See Table 34). The majority of income losses, however; roughly 75% occur with commercial structures. Residential buildings make-up another 15% with the remaining occupancy types filling the final 10%. As with the previous table, all building related economic losses total nearly $8.4 billion.

Table 33: Direct Losses for Buildings by State ($ thousands) – NE Level I

	Capital Losses					**Income Losses**				
	Structural Damage	**Non-Structural Damage**	**Contents Damage**	**Inventory Loss**	**Loss Ratio**	**Relocation Loss**	**Capital Related Loss**	**Wages Loss**	**Rental Income Loss**	**Total Loss**
Alabama	$483	$3,043	$1,568	$72	0.01	$4	$78	$115	$132	**$5,495**
Arkansas	$16,379	$53,730	$22,787	$1,066	0.12	$292	$4,137	$5,447	$4,627	**$108,465**
Illinois	$465,679	$1,166,272	$347,166	$7,590	4.13	$10,269	$101,092	$133,114	$132,384	**$2,363,565**
Indiana	$68,036	$80,709	$39,071	$3,099	0.26	$670	$10,674	$12,809	$8,255	**$223,325**
Kentucky	$216,021	$511,715	$165,776	$5,528	2.30	$4,877	$62,694	$87,796	$62,428	**$1,116,836**
Mississippi	$2,275	$10,541	$5,496	$405	0.03	$28	$489	$695	$636	**$20,564**
Missouri	$721,701	$2,006,476	$661,191	$23,851	2.58	$15,458	$185,216	$243,106	$214,097	**$4,071,096**
Tennessee	$97,278	$279,122	$115,332	$4,202	0.54	$2,085	$30,690	$41,916	$30,250	**$600,875**
TOTAL	***$1,587,852***	***$4,111,609***	***$1,358,387***	***$45,813***		***$33,684***	***$395,070***	***$524,997***	***$452,808***	***$8,510,220***

Table 34: Direct Economic Losses by General Occupancy ($ millions) – NE Level I

		Single Family	Other Residential	Commercial	Industrial	Others	TOTAL
Income Losses	**Wage**	$0.00	$18.92	$464.59	$19.24	$22.25	**$525.00**
	Capital-Related	$0.00	$8.27	$367.61	$12.18	$7.02	**$395.08**
	Rental	$110.12	$111.66	$202.15	$7.11	$9.04	**$440.08**
	Relocation	$12.09	$4.46	$13.38	$0.65	$3.10	**$33.68**
	SUBTOTAL	**$122.21**	**$143.31**	**$1,047.73**	**$39.18**	**$41.41**	**$1,393.84**
Capital Stock Losses	**Structural**	$542.42	$343.60	$477.15	$88.69	$135.99	**$1,587.85**
	Non-Structural	$1,807.04	$1,033.46	$905.19	$171.77	$194.15	**$4,111.61**
	Content	$578.46	$198.25	$386.37	$102.28	$93.02	**$1,358.38**
	Inventory	$0.00	$0.00	$16.98	$24.00	$4.83	**$45.81**
	SUBTOTAL	**$2,927.92**	**$1,575.31**	**$1,785.69**	**$386.74**	**$427.99**	**$7,103.65**
	TOTAL	***$3,050.13***	***$1,718.62***	***$2,833.42***	***$425.92***	***$469.40***	***$8,497.49***

Direct economic losses for transportation systems are detailed in Table 35 by state and appear in thousands of dollars. As with building losses, Illinois and Missouri experience the greatest amounts of loss at nearly $109 million and $164 million, respectively. Mississippi and Alabama see the least economic losses which is due to the significantly smaller number of census tracts as well as reduced ground motion. Transportation losses are also quantified by transportation subsystems and their respective components as seen in Table 36 displayed in millions of dollars. Loss ratios indicate the total loss of ferries and significant economic losses incurred by railway facilities, bus facilities, port facilities and airport facilities. As mentioned earlier segment damage for railways and highways is not calculated due to a lack of liquefaction information.

Table 35: Direct Transportation Losses by State ($ thousands) – NE Level I

	Transportation							
	Highway	**Railway**	**Light Rail**	**Bus Facility**	**Ports**	**Ferries**	**Airports**	**Total**
Alabama	$1,294	$123	$0	$18	$641	$0	$518	**$2,593**
Arkansas	$28,403	$944	$0	$98	$2,255	$0	$11,784	**$43,484**
Illinois	$14,301	$10,677	$0	$1,407	$22,646	$2,420	$57,990	**$109,441**
Indiana	$247	$2,317	$0	$51	$3,969	$0	$9,327	**$15,911**
Kentucky	$9,828	$8,287	$0	$348	$27,912	$1,068	$16,284	**$63,727**
Mississippi	$6,144	$70	$0	$29	$408	$0	$2,666	**$9,317**
Missouri	$65,831	$16,378	$0	$2,964	$34,742	$1,123	$43,028	**$164,066**
Tennessee	$53,070	$2,831	$0	$487	$7,197	$959	$14,939	**$79,484**
TOTAL	***$179,119***	***$41,627***	***$0***	***$5,403***	***$99,769***	***$5,570***	***$156,535***	***$488,023***

Table 36: Direct Transportation Losses by Subsystem Component – NE Level I

	Inventory Value	Economic Loss	Loss Ratio
Highway Bridges	$25,505,730,000	$179,120,000	0.70%
Railway Bridges	$53,160,000	$50,000	0.10%
Railway Facilities	$830,860,000	$41,570,000	5.00%
Bus Facilities	$90,310,000	$5,400,000	5.98%
Ferry Facilities	$5,570,000	$5,570,000	100.00%
Port Facilities	$1,413,120,000	$99,770,000	7.06%
Airport Fcilities	$3,366,410,000	$156,540,000	4.65%

The final category of direct economic losses is utility systems. Losses are classified by state and represented in thousands of dollars in Table 37. As with the two previous direct loss categories Illinois and Missouri realize the greatest damage values at $1.3 and $1.5 million, respectively. Additional utility losses based on facility type and component are found in Table 38 Numerous components show loss ratios greater than one, including potable water facilities and distribution lines, waste water facilities, natural gas facilities and distribution lines electric facilities and communication facilities. Total utility losses are nearly $3.5 billion.

Table 37: Utility Systems by State ($ thousands) – NE Level I

	Utility Systems						
	Potable Water	Waste Water	Oil Systems	Natural Gas	Electric Power	Communication	Total
Alabama	$1,396	$1,852	$0	$1,106	$640	$3	**$4,996**
Arkansas	$9,361	$72,100	$2	$6,500	$9,441	$53	**$97,456**
Illinois	$129,306	$994,165	$13	$32,108	$140,007	$573	**$1,296,173**
Indiana	$5,626	$20,990	$4	$2,337	$10,211	$34	**$39,201**
Kentucky	$41,405	$233,386	$1	$10,866	$50,598	$286	**$336,542**
Mississippi	$2,770	$7,433	$0	$2,232	$773	$7	**$13,217**
Missouri	$143,587	$1,192,504	$10	$36,177	$141,417	$777	**$1,514,472**
Tennessee	$19,393	$134,596	$7	$10,643	$10,066	$169	**$174,874**
TOTAL	***$352,843***	***$2,657,027***	***$36***	***$101,969***	***$363,153***	***$1,902***	**$3,476,931**

When all losses are totaled direct economic losses equate to approximately $12.5 billion for the entire study region. These losses are broken down according to Table 39. Roughly 45% of all direct losses are sustained by Missouri with another 30% incurred by Illinois. Kentucky experiences another 12% of all direct economic losses and the remaining states compose the final 13%. Buildings sustain approximately two-thirds of the total direct economic losses, with another 28% accounted for utility losses and only 4% are attributed to transportation losses. These estimates indicate the crucial nature of building damage to regional loss assessment, though this analysis does not account for roadway and railway segment damage, or utility pipelines used for transmission. These data items will be included in subsequent analyses for later comparison with this baseline scenario for the northeast epicenter.

Table 38: Utility System Losses by Subcomponent – NE Level I

	Inventory Value	Economic Loss	Loss Ratio
Potable Water Facilities	$8,314,300,000	$234,760,000	2.82%
Potable Water Distribution Lines	$10,011,200,000	$118,080,000	1.18%
Waste Water Facilities	$108,128,400,000	$2,563,630,000	2.37%
Waste Water Distribution Lines	$6,006,700,000	$93,390,000	1.55%
Natural Gas Facilities	$117,100,000	$2,140,000	1.82%
Natural Gas Distribution Lines	$4,004,500,000	$99,830,000	2.49%
Oil Facilities	$4,800,000	$40,000	0.75%
Electric Power Facilities	$17,087,400,000.00	$363,150,000.00	2.13%
Communication Facilities	$89,600,000.00	$1,900,000.00	2.12%

Table 39: Total Direct Economic Loss – NE Level

	Total Loss
Buildings	$8.5
Transporation	$0.5
Utilities	$3.5
Total	**$12.5**

Additional impacts are calculated for indirect losses, or losses due to business downtime and loss of work time. These values are determined for the first five years after an earthquake with additional predictions up to 15 years after an earthquake. Losses are displayed in millions of dollars and in numbers of employees. The first three years show induced losses for both employment and income on the order of $27.1 billion and 6.9 million jobs gained. By the fourth year income gains begin, as denoted by the value in parentheses. Additionally, loss ratios become negative in the fourth year, indicating recovery of the regional economy (See Table 40). The region continues to recover up to the fifth year after the applied earthquake.

Table 40: Indirect Economic Losses without Aid – NE Level I

	Loss	Total	%
First Year	Employment Impact	5,092,278	171.00
	Income Impact	16,550	11.67
Second Year	Employment Impact	1,790,617	60.13
	Income Impact	8,468	5.97
Third Year	Employment Impact	40,807	1.37
	Income Impact	2,101	1.48
Fourth Year	Employment Impact	2,299	0.08
	Income Impact	-135	-0.10
Fifth Year	Employment Impact	131	0.00
	Income Impact	-261	0.18
Years 6 to 15	Employment Impact	7	0.00
	Income Impact	-268	-0.19

6.1.2 Central Epicenter

6.1.2.1 Ground Motion

The second epicenter considered in this research is located on the northern tip of the Missouri and Tennessee border. This position is chosen to determine the impact of centrally located earthquake on the New Madrid Seismic Zone. Hazard maps illustrating the shaking of the study region are shown in Figure 62-Figure 65. Peak ground accelerations of 0.67*g* exist in the few census tracts the surround the epicenter, beyond which PGA values decrease rapidly. Moderate shaking, quantified by PGA values between 0.35*g* and 0.1*g*, are experienced throughout the majority of the region, with the exception of tracts within 40 km of the epicenter. Very few tracts fall outside the PGA threshold-defined area of less than 0.05*g*. Only corners of the study region see such minimal shaking values. Similar trends exist for peak ground velocity, with regional maximum values reaching approximately 30 in./sec.

Spectral accelerations, in particular short-period accelerations, include a much broader range of moderate shaking. Nearly the entire breadth of the region experiences short-period spectral accelerations greater than 0.1*g*. Only northern and southern bands of census tracts show minimal acceleration values. As expected, tracts near the epicenter encounter severe shaking upwards of 1*g*, maxing out at 1.67*g*. Maximum long-period spectral accelerations are roughly half that of short-period values at identical source-to-site distances. Nearest the epicenter S_a at 1.0 seconds reaches 0.8*g*, and decreases rapidly from there. The hazard map indicates that nearly 75% of the region experiences long-period spectral accelerations less than 0.2*g*.

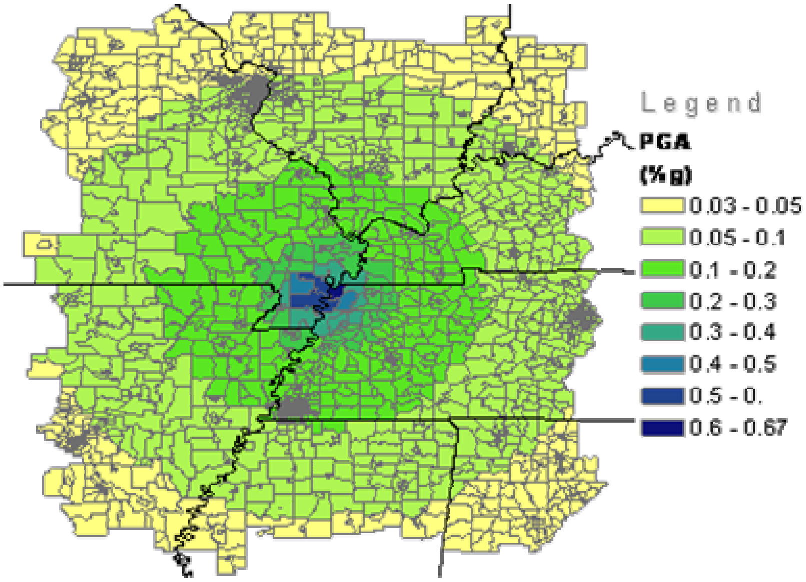


Figure 62: Central Epicenter PGA (g) – Central Level I

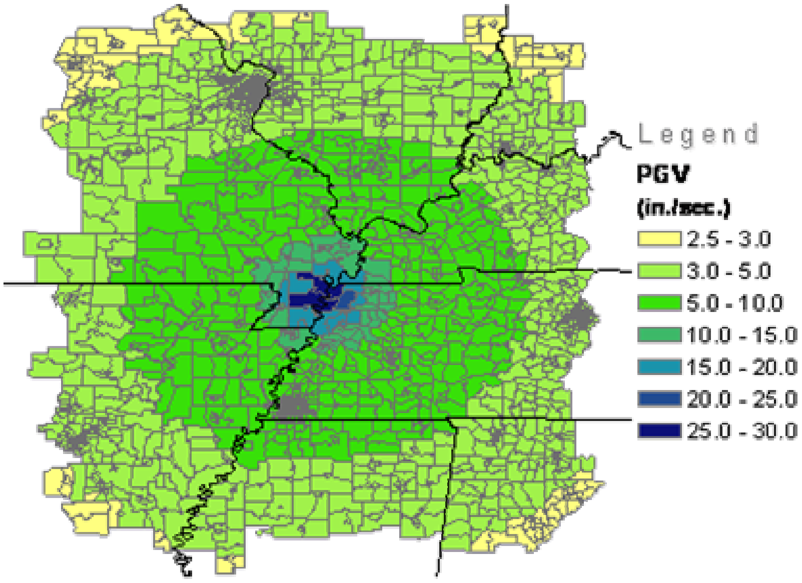


Figure 63: Central Epicenter PGV (in./sec.) – Central Level I

The regional hazard is also characterized by additional shaking parameters including spectral displacement. As shown in Figure 66 & Figure 67, maximum short-period spectral displacement is 3.15-inches along the Tennessee/Missouri border. More common regional values are less than one-inch, with the exception of those census tracts within 75 km of the epicenter. Long-period spectral displacements are considerably

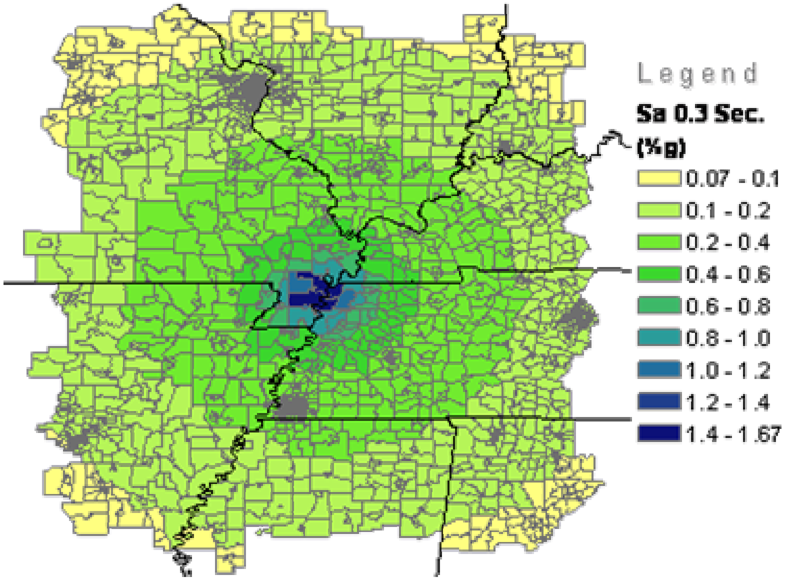


Figure 64: Central Epicenter S_a 0.3 sec. (g) – Central Level I

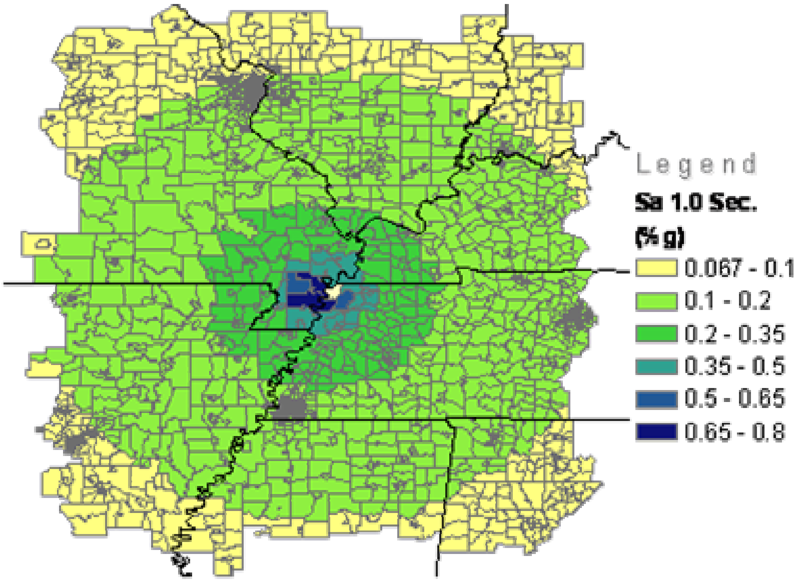


Figure 65: Central Epicenter S_a 1.0 sec. (g) – Central Level I

higher, with a maximum displacement value of 5.04-inches. This is approximately 60% greater than the short-period maximum displacement. Lesser displacements are seen across the study region, with most census tracts experiencing displacements less than 1.5-inches. Despite the reduction of displacement as source-to-site distances increases, structures still undergo damage-causing deflections. Displacements of ¼-inch are enough to cracks some glass and one-inch deflections are likely to crack architectural finishes and most types of glass, particularly interior glass.

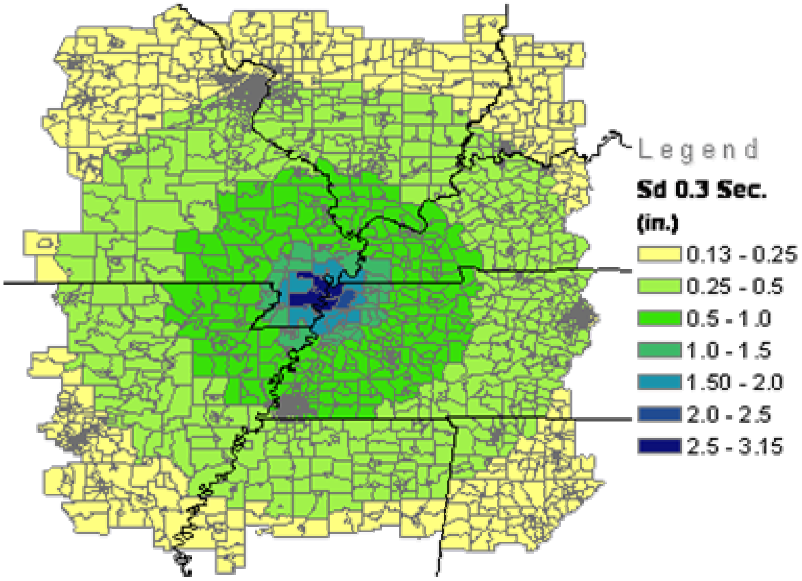


Figure 66: Central Epicenter S_d 0.3 sec. (in.) – Central Level I

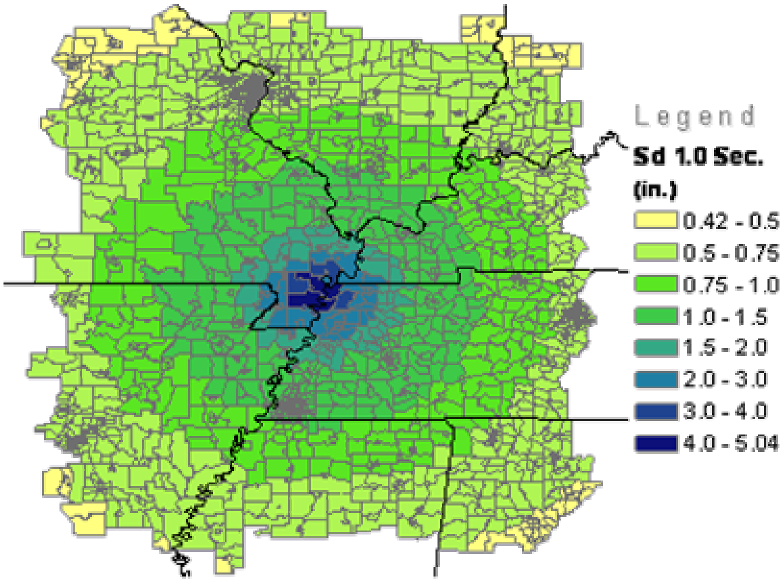


Figure 67: Central Epicenter S_d 1.0 sec. (in.) – Central Level I

6.1.2.2 General Building Stock

As with the northeast epicenter, damage to the general building stock focuses on damage to three primary specific building types; light wood frame, low-rise unreinforced masonry and mobile homes. Structural damage state probabilities representing the likelihood of at least moderate damage to these three building types are illustrated in Figure 68 - Figure 70. Light wood frame buildings, W1, show less than 10% probability

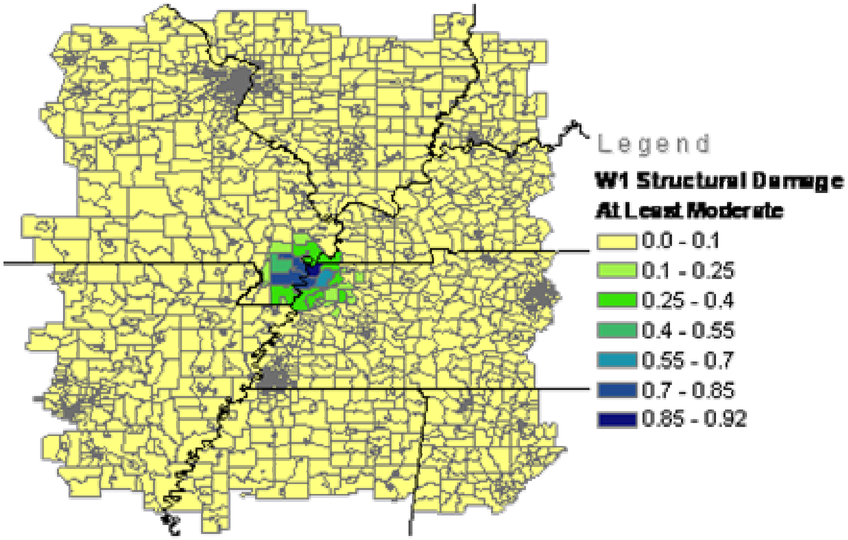


Figure 68: At Least Moderate Structural - W1 – Central Level I

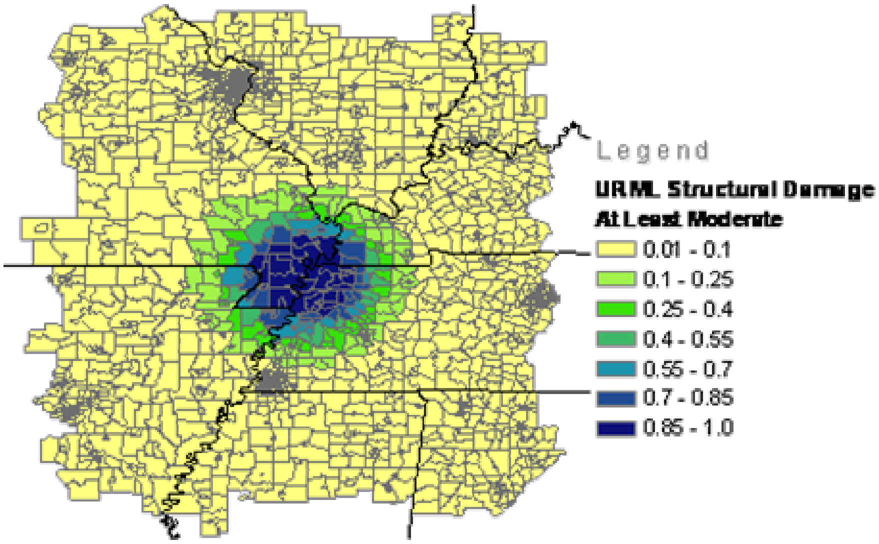


Figure 69: At Least Moderate Structural - URML – Central Level I

of suffering at least moderate damage over nearly the entire region. Only within 40 km of the epicenter are W1 buildings more than 10% likely to reach the aforementioned damage state. The behavior of light wood frame buildings completely contrasts that of URMs and mobile homes. Both of these building types show extensive areas within which buildings are likely to sustain at least moderate damage. Low-rise unreinforced masonry (URML) structures show a region of greater than 55% probability of realizing at least moderate damage which extends approximately 100 km from the epicenter. Beyond this source-to-site distance, this damage state decreases to less than 10% over a short distance, roughly 40-50 km. Mobile homes exhibit a similar trend for high damage state probabilities. Within 100 km of the epicenter the likelihood of at least moderate damage is 55% or greater. Mid- range probabilities, however; extend for nearly another 100 km before falling below 10% likelihood of at least moderate structural damage.

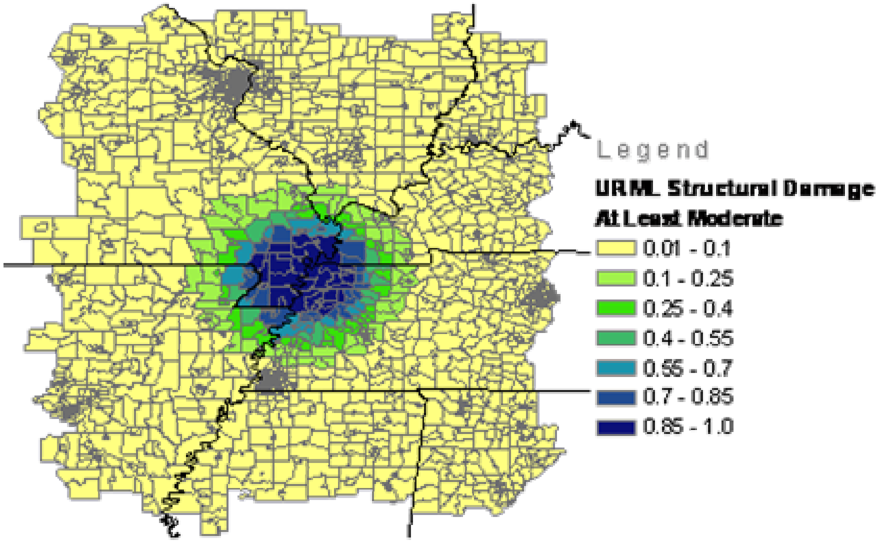


Figure 70: At Least Moderate Structural - MH – Central Level I

Non-structural damage state probability distributions mimic those of their structural damage probability counterparts. Damage state probabilities for acceleration and drift dependent non-structural components are detailed in Figure 71 & Figure 72 for unreinforced masonry low-rises. The likelihoods of at least moderate damage are vastly different for acceleration-controlled equipment and drift-controlled building contents. Acceleration-dependent damage probabilities are high only nearest the epicenter then taper to less than 10% over the ensuing 100 km, approximately. Drift-sensitive damage components, however; show high probabilities of at least moderate damage for the first 75 km then reduce to less than 10% within another 30-40 km. The other primary building types show similar trends, though light wood frame damage is consolidated into a much smaller area around the epicenter, similar to that of the structural damage probability figure for at least moderate damage. Conversely, mobile homes are expected to cover a slightly larger area as its corresponding structural damage area does.

Further estimates of damage to the general building stock are quantified by building count and total square footage. Table 41 highlights damage to the three primary building types as specified by seismic design level. Light wood frames sustain significant damage with regard to the number of buildings, though the overall percentage of damaged buildings is low, less than 5%. Other notable results for light wood frames include the collapse rate, almost a negligible percentage of the total building stock, at only 57 buildings out of a total 2.75 million structures. Unreinforced masonry buildings do not fare as well, with over 16% of all buildings experiencing some damage. The collapse rate of 0.4% is over 100 times greater than that of light wood frames. Mobile

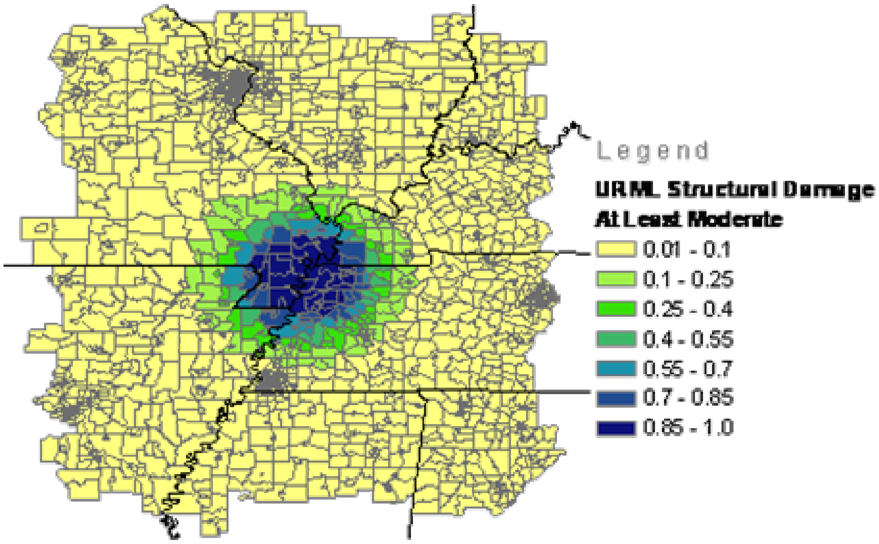


Figure 71: Non-Structural Acceleration - URML – Central Level I

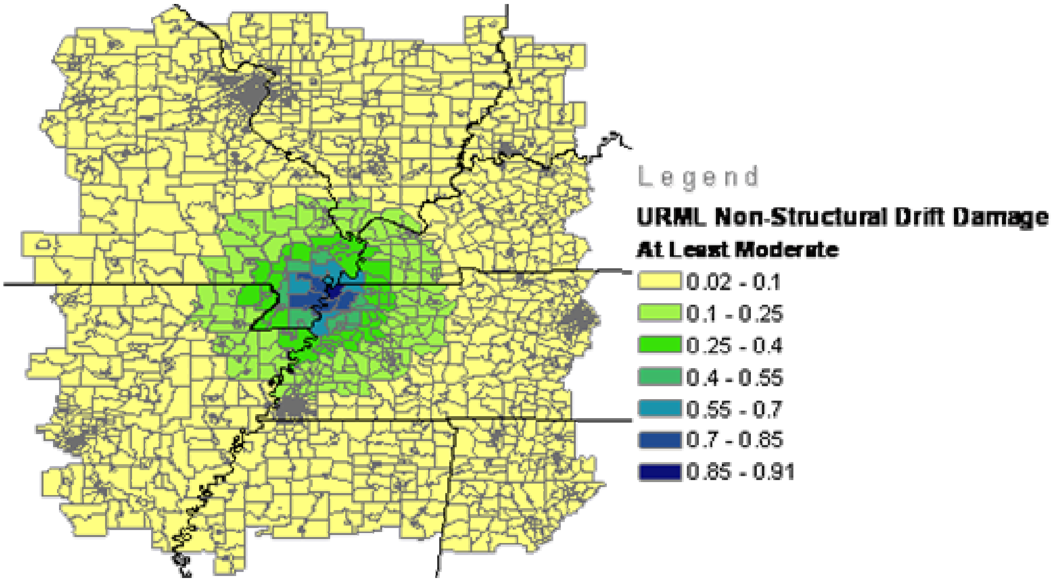


Figure 72: Non-Structural Drift - URML – Central Level I

homes also experience significant damage as nearly 60% of all structures see some form of damage. Also noteworthy is the large proportion of mobile homes sustaining slight and moderate damage. These damage states are classified as damage and/or separation

Table 41: Damage by Building Count and Seismic Design Level – Central Level I

	Light Wood Frame				
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Buildings	406,948	69,146	11,789	889	57
Total Low Code Buildings	2,217,682	45,582	2,414	15	0
Total Buildings	**2624630**	**114728**	**14203**	**904**	**57**
		Total Number of Building Type:			2754522
%Total Buildings	***95.284%***	***4.165%***	***0.516%***	***0.033%***	***0.002%***
	Unreinforced Masonry				
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Buildings	30418	14622	9754	3738	1154
Total Low Code Buildings	167479	9023	1990	199	12
Total Pre-Code Buildings	242092	31143	10350	2462	980
Total Buildings	**439989**	**54788**	**22094**	**6399**	**2146**
		Total Number of Building Type:			525416
%Total Buildings	***83.741%***	***10.428%***	***4.205%***	***1.218%***	***0.408%***
	Mobile Homes				
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Buildings	9932	14466	16761	3834	383
Total Low Code Buildings	145538	17473	7399	403	0
Total Pre-Code Buildings	141412	56641	57026	11997	1316
Total Buildings	**296882**	**88580**	**81186**	**16234**	**1699**
		Total Number of Building Type:			484581
%Total Buildings	***61.266%***	***18.280%***	***16.754%***	***3.350%***	***0.351%***

Table 42: Building Damage by Square Footage and Seismic Design Level – Central Level I

	Light Wood Frame				
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Square Footage	722,111,310	120,964,690	20,707,010	1,610,420	106,560
Total Low Code Square Footage	3,928,967,730	78,886,710	4,252,080	34,340	60
Total Square Footage	**4,651,079,040**	**199,851,400**	**24,959,090**	**1,644,760**	**106,620**
		Total Number of Square Footage Type:			4,877,640,910
%Total Square Footage	***95.355%***	***4.097%***	***0.512%***	***0.034%***	***0.002%***
	Unreinforced Masonry				
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Square Footage	87396180	38704930	23897240	9042490	2802150
Total Low Code Square Footage	389646860	21107730	5190740	529160	30390
Total Pre-Code Square Footage	668915330	87206990	29108720	6995980	2570210
Total Square Footage	**1,145,958,370**	**147,019,650**	**58,196,700**	**16,567,630**	**5,402,750**
		Total Number of Square Footage Type:			1,373,145,100
%Total Square Footage	***83.455%***	***10.707%***	***4.238%***	***1.207%***	***0.393%***
	Mobile Homes				
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Square Footage	10850170	15816030	18423200	4279500	437860
Total Low Code Square Footage	158403250	18980340	8111280	459620	1710
Total Pre-Code Square Footage	154414510	61612890	61948920	13124880	1505510
Total Square Footage	**323,667,930**	**96,409,260**	**88,483,400**	**17,864,000**	**1,945,080**
		Total Number of Square Footage Type:			528,369,670
%Total Square Footage	***61.258%***	***18.247%***	***16.746%***	***3.381%***	***0.368%***

from attached components such as porches and stairs and complete detachment of porches and rocking of the structures which requires resetting the home on its supports for slight and moderate damage, respectively. As with URMs, mobile homes show a collapse rate approximately 100 times that of the rate for light wood frames.

Moreover, damage state determinations are quantified by total square footage per building type. Table 42 illustrates the distribution of building type damage by square footage. These measures of damaged floor area correlate well to estimates of damage by building count with regard to percentages of the building stock regional square footage.

Table 43: Number of Buildings Damaged by State – Central Level I

	Low-Code					
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**	**Total**
Alabama	204,690	778	28	0	0	**205,496**
Arkansas	341,512	3,029	182	1	0	**344,724**
Illinois	324,995	7,153	839	17	0	**333,005**
Indiana	127,819	609	22	0	0	**128,450**
Kentucky	175,179	13,316	2,752	137	1	**191,385**
Mississippi	225,994	5,981	426	4	0	**232,406**
Missouri	662,091	6,839	529	6	0	**669,465**
Tennessee	476,469	34,884	7,575	525	14	**519,466**
Code Total	**2,538,749**	**72,590**	**12,353**	**690**	**15**	**2,624,396**
	Moderate-Code					
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**	**Total**
Alabama	0	0	0	0	0	**0**
Arkansas	111,650	25,076	7,656	952	46	**145,380**
Illinois	7,444	2,452	1,077	71	1	**11,045**
Indiana	0	0	0	0	0	**0**
Kentucky	4,945	3,199	1,568	287	29	**10,028**
Mississippi	0	0	0	0	0	**0**
Missouri	48,119	25,906	16,402	4,597	1,060	**96,083**
Tennessee	278,692	42,534	12,108	2,682	483	**336,498**
Code Total	**450,851**	**99,167**	**38,811**	**8,588**	**1,618**	**599,035**
Region Total	**2,989,600**	**171,757**	**51,164**	**9,279**	**1,632**	**3,223,431**
% Region Total	***92.746%***	***5.328%***	***1.587%***	***0.288%***	***0.051%***	

Table 44: Damage by State – Central Level I

	No. Buildings Damage	**% of Total Building Stock**
Alabama	4,886	0.13%
Arkansas	56,638	1.49%
Illinois	39,102	1.03%
Indiana	3,427	0.09%
Kentucky	44,042	1.16%
Mississippi	23,799	0.62%
Missouri	91,033	2.39%
Tennessee	148,595	3.90%

Just as the location of the epicenter plays a critical role in the overall value of regional damage it is also a crucial factor when damage is evaluated by state. A central epicenter will cause greater damage to central states as oppose to northern or southern portions of the study region. This is evident in damage determinations by state as shown in Table 43. Regionally, over 90% of the general building stock experiences no damage while nearly three-quarters of the remaining 7% is attributed to slight damage. This indicates that approximately 2%, or over 62,000 buildings undergo moderate, extensive or complete damage. Furthermore, state data reveals that Missouri and Tennessee experience the greatest numbers of damaged buildings as shown in Table 44. While roughly half of all regional buildings are located in Missouri and Tennessee two-thirds of all damaged buildings are located there. This estimate includes all damage states, not just those buildings exceeding moderate damage.

Table 45: Building Damage by General Occupancy – Central Level I

	None		Slight		Moderate		Extensive		Complete	
	Count	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**
Agriculture	1,976	0.06%	134	0.05%	62	0.05%	24	0.10%	10	0.25%
Commercial	30,266	0.89%	3,707	1.41%	2,154	1.78%	565	2.31%	90	2.22%
Education	260	0.01%	23	0.01%	12	0.01%	2	0.01%	0	0.00%
Government	1,463	0.04%	155	0.06%	91	0.08%	20	0.08%	6	0.15%
Industrial	4,829	0.14%	645	0.25%	485	0.40%	143	0.58%	18	0.44%
Other Residential	420,861	12.38%	96,042	36.62%	83,486	69.17%	16,842	68.72%	1,890	46.53%
Religion	2,311	0.07%	231	0.09%	116	0.10%	32	0.13%	8	0.20%
Single Family	2,936,595	86.41%	161,318	61.51%	34,286	28.41%	6,881	28.08%	2,040	50.22%
TOTAL	**3,398,561**		**262,255**		**120,692**		**24,509**		**4,062**	

Lastly, damage is classified by general occupancy type as shown in Table 45. Damage percentages are greatest for residential buildings, though this is likely due to the large number of residential structures in comparison to the remaining occupancy types. Commercial structures do not occupy large damage percentages for slight and no damage categories, though they comprise over 2% of collapsed buildings. This is the case for agricultural buildings as well, incurring greater overall loss percentages with increasing damage state, perhaps indicating that these structures are not as well-suited to resist collapse as residential structures are.

6.1.2.3 Essential Facilities

Essential facilities damage is similar to that of unreinforced masonry buildings, since most essential facilities are assigned that building type. A diagram illustrating the regional probability of at least moderate damage appears in Figure 73. Higher probabilities of damage exist near the epicenter, as expected, though moderate probabilities extend to the east and west in a somewhat non-concentric fashion. This behavior is due to the pre-code seismic design level assigned to buildings in those areas and a higher vulnerability to seismic activity than the moderate code building present in the center of the region. While only damage to fire stations is pictured here damage state probabilities for the remaining essential facilities replicate this behavior, with minor deviations of source-to-site distance ranges for the damage state probabilities listed.

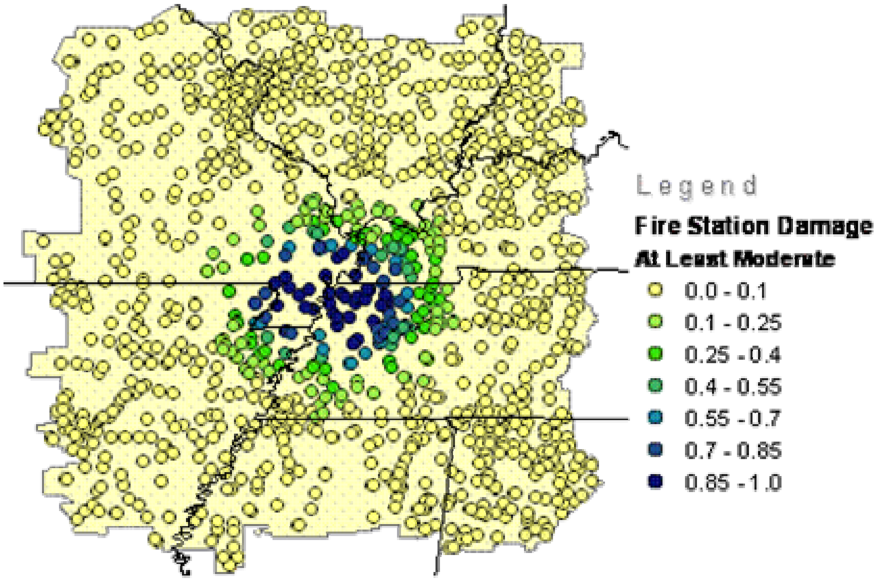


Figure 73: At Least Moderate Damage - Fire Stations – Central Level I

Table 46: Essential Facilities Damage - NE Level I

Classification	Total	No. of Facilities Moderate Damage >50%	Complete Damage >50%
Hospitals	308	28	0
Schools	4,695	220	13
EOCs	92	8	0
Police Stations	1,207	103	6
Fire Stations	1,465	101	5

Essential facilities damage is illustrated in Table 46. Hospitals show the greatest percentage of at least moderate damage, at roughly 9% of the total inventory. Fire stations show a significantly lesser percentage of damaged inventory at roughly 7% experiencing at least moderate damage. Schools incur the most cases of complete damage, though this is still only 5% of all regional schools which are situated nearest the source of seismic activity. EOCs still show the greatest percentage of damage with roughly 10% of all facilities experiencing complete damage. No hospitals show complete damage which does not substantially limit the number of beds available to treat injured persons in the aftermath of an earthquake.

Table 47: Essential Facilities Functionalities – Central Level I

	Hospitals		Fire Stations		Police Stations		Schools	
	308 Total Strucutres		1465 Total Strucutres		1207 Total Strucutres		4695 Total Strucutres	
	No. Functional	% of Total Functional	No. Functional	% of Total Functional	No. Functional	% of Total Functional	No. Functional	% of Total Functional
Day 1	268	87.01%	1216	83.00%	1020	84.51%	4181	89.05%
Day 3	270	87.66%	1224	83.55%	1025	84.92%	4194	89.33%
Day 7	280	90.91%	1362	92.97%	1104	91.47%	4470	95.21%
Day 14	280	90.91%	1364	93.11%	1104	91.47%	4475	95.31%
Day 30	303	98.38%	1444	98.57%	1181	97.85%	4637	98.76%
Day 90	308	100.00%	1455	99.32%	1194	98.92%	4668	99.42%

Functionalities for essential facilities are also determined across the region. Fire and police stations fare the worst with less 85% of facilities operational the day after an earthquake. This lack of functionality, particularly nearest the epicenter, is likely to affect the response of aid personnel immediately after the earthquake and must be considered in response and recovery plans. Recovery of approximately 150 fire stations as well as 85 police stations occurs in the first two weeks after an earthquake, equating to greater than 90% of all facilities functioning. Hospitals are not as quick to recover with only 36,608 hospitals beds available the day of the earthquake, or 76% of regional beds. After two weeks 91% of hospitals are functional, though not those in the hardest hit areas near the epicenter (See Table 47). School, however, have over 95% of all buildings operational within the first week after an earthquake. Despite this high percentage it is important to note that there are still over 200 schools which are non-functional. Even after three months 27 schools are still unusable which requires the relocation of thousands of students. As expected schools nearest the epicenter comprise all the non-functional schools at the 90-day period.

6.1.2.4 Transportation Systems

One of the primary subcomponents of the transportation system is the highway network. Without liquefaction information none of the roadway damage is calculated, leaving only bridge damage. Only bridges within 40 km of the epicenter are more than 10% likely to collapse, with no single bridge more than 60% likely to collapse. At least moderate bridge damage state probabilities extend farther into the region, with 10% likelihood of meeting or exceeding this damage state as far as 200 km from the epicenter. Total bridge losses resulting from all damage states are predicted to exceed $177 million for an earthquake along the central thrust of the New Madrid Fault.

Table 48: Highway Bridge Functionalities – Central Level I

Highway Bridge Fuctionality

Time	No. Functional	% Total Functional
Day 1	29957	98.82%
Day 3	30085	99.24%
Day 7	30119	99.36%
Day 14	30124	99.37%
Day 30	30158	99.49%
Day 90	30254	99.80%

Damage to bridges directly correlates to bridge functionality. The number of functional bridges at various time periods after an earthquake is displayed in Table 48. Initially over 98% of bridges are functional, though this high percentage equates to over 350 bridges that are not useable. This number is nearly cut in half after one week, with only 60 bridges not operating three months after the earthquake. These remaining bridges, within 30 km of the epicenter, are most likely to collapse or experience severe damage resulting from intense shaking.

Railway subsystem damage is divided into railways and railway facilities. A centrally located earthquake estimated low damage probabilities for only a few bridges, resulting in $50,000 of loss, while the remaining bridges are not at all likely to see damage. The related facilities, however; generate much higher losses which are approximately $39 million. The damage state probability distribution is illustrated in Figure 74, which shows that the bridges expected to incur significant damage are along the Mississippi River in Tennessee and southern Missouri. Highway bridge damage mimics this behavior, though the network is much denser.

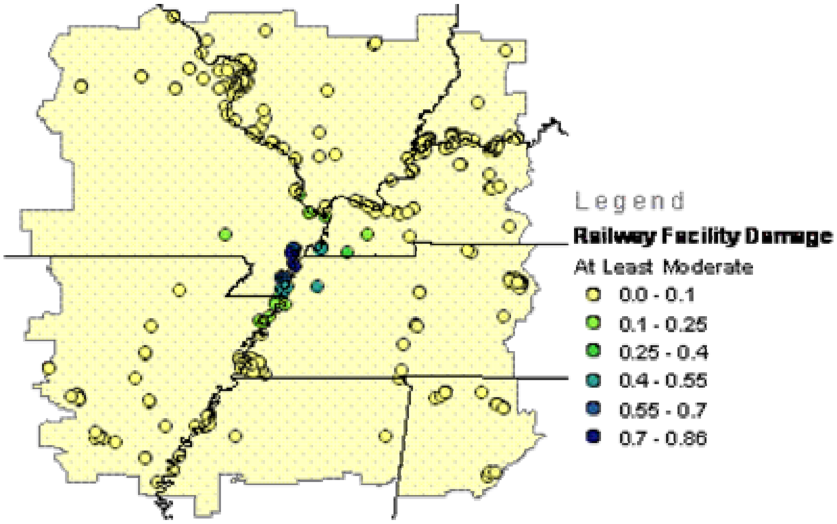


Figure 74: At Least Moderate Damage - Railway Facilities – Central Level

Table 49: Transportation Systems Damage & Functionality – Central Level I

	Region Total	At Least Moderate Damage	Complete Damage	With > 50% Functionality	
				Day 1	Day 7
Highway Bridges	30,314	371	7	29,951	30,119
Railway Bridges	425	0	0	425	425
Railway Facilities	393	20	0	389	393
Bus Facilities	84	1	0	84	84
Ferry Facilities	5	5	5	0	0
Port Facilities	691	17	0	683	691
Airport Facilities	637	6	0	634	637

The remaining transportation subsystems, their damage and functionalities are detailed in Table 49. Airport facilities are not expected to sustain much damage as a subsystem, as only six facilities are predicted to sustain moderate damage or greater. When slight damage is added in however; airport facility loss values skyrocket to over \$147 million. Seventeen port facilities are expected to incur damage, which contributes to the over \$83 million in losses. All ferry facilities experience at least moderate damage that result in \$5.6 million in loss, or \$1.1 million per facility, which is also true of the northeast epicenter. This is possible for the two overlapping facilities on the Kentucky/Missouri border, though not so likely for the outlying facilities in Tennessee and Illinois (Figure 75). These results bring into question the accuracy and reliability of HAZUS-MH and its calculations as it is unlikely all of these facilities collapse. This is an area that may require intervention by HAZUS-MH developers.

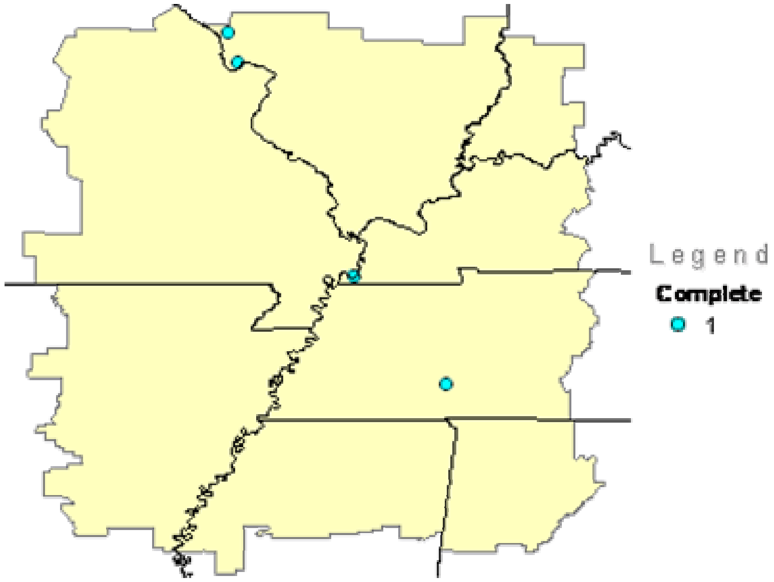


Figure 75: Complete Damage - Ferry Facilities – Central Level I

6.1.2.5 Utility Systems

Utility facilities damage for all facilities types resembles that seen in the general building stock. An example map of utility facilities damage state probabilities for at least moderate damage is depicted by the waste water facilities in Figure 76. Radiating damage is shown, with the greatest damage probabilities nearest the epicenter. In light of the damage probabilities seen with ferry facilities it is relevant to note that there are no outlying utility facilities predicted to collapse. Table 50 also provides damage state quantities for each type of utility facilities. According to the HAZUS-MH analysis no utility facilities experience complete damage, though numerous structures are predicted to experience at least moderate damage. Potable water facilities exhibit the highest damage rate at nearly 3% of facilities damaged, while the remaining facilities show approximately 1% or less.

Functionalities for all types of utility systems indicate that every utility facility is operational 90 days after an earthquake. All but waste water facilities, in fact, are fully operational only three days after an earthquake. This trend is due to the locations of facilities in relation to the epicenter. Most structures do not lie within the few tracts nearest the epicenter where the most intense shaking occurs. Table 51 displays the number of operational facilities at various post-earthquake intervals.

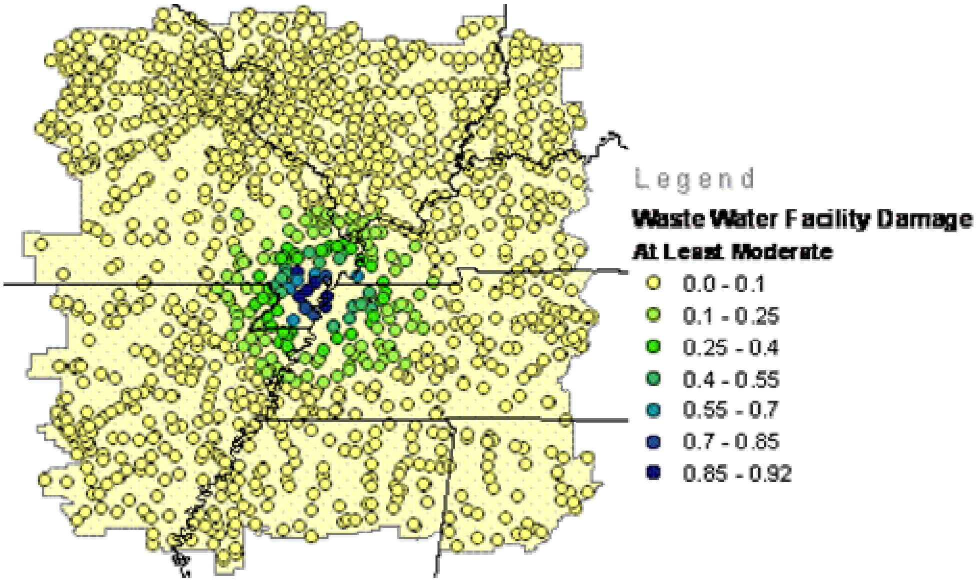


Figure 76: At Least Moderate Damage - Waste Water Facilities – Central Level I

Table 50: Utility Systems Damage & Functionality – Central Level I

	Region Total	At Least Moderate Damage	Complete Damage	With > 50% Functionality	
				Day 1	Day 7
Potable Water	249	7	0	242	249
Waste Water	1,646	22	0	1,565	1,643
Natural Gas	114	0	0	113	114
Oil	49	0	0	19	49
Electric Power	158	2	0	149	158
Communications	940	11	0	938	940

Table 51: Utility Systems Functionality – Central Level I

	Utility Facilities Functionality						
	Day 1	Day 3	Day 7	Day 14	Day 30	Day 90	Total
Potable Water	242	249	249	249	249	249	**249**
Waste Water	1565	1632	1643	1643	1644	1646	**1646**
Natural Gas	113	114	114	114	114	114	**114**
Oil Systems	49	49	49	49	49	49	**49**
Electric Power	149	158	158	158	158	158	**158**
Communication	938	940	940	940	940	940	**940**

Utility system performances are also quantified by service disruption, such as breaks and leaks in pipelines as well as the number of customers with suspended service due to system damage. Breakage and leakage are detailed in Table 52 for potable and waste water systems and oil and natural gas distribution networks. It is relevant to note that this scenario employs default data only and thus HAZUS-MH default pipeline assumptions, instead of actual pipeline distribution networks, are used to determine these service disruptions. Potable water pipelines display the greatest number of both breaks and leaks, while waste water lines experience the least. Natural gas lines possess the largest leak rate, 0.10 leaks/km, with both water networks at 0.06 leaks/km or less. Natural gas lines also exhibit the largest break rate of 0.026 break/km.

Table 52: Pipeline Damage – Central Level I

	Pipeline Length	Number of Leaks	Number of Breaks
Potable Water	500,560	24,462	6,115
Waste Water	300,336	19,347	4,837
Natural Gas	200,224	20,681	5,170
Oil	0	0	0

Table 53: Electric and Potable Water Service Disruptions – Central Level I

		No. of Households without Service				
	Total No. Households	Day 1	Day 3	Day 7	Day 30	Day 90
Potable Water	4,236,197	43,821	25,522	10,078	0	0
Electric Power		29,923	17,023	5,921	972	39

Electric and potable water are also classified by service interruptions, as shown in Table 53. Potable water is restored to all regional households within 30 days of an earthquake, while electric power is not fully restored for more than three months. Even with the rapid recovery rate of potable water line there are still nearly 44,000 households, or 1.4% of all regional households, without water the day after the earthquake. This is in contrast to less than 1% of households without electric power.

Finally, utility systems are characterized by individual subsystem losses. Table 54 highlights losses by subsystem. The waste water system incurs the greatest economic loss at over $1.7 billion and over 71% of all utility losses. The electric system sustains the second largest losses at about 11.1% of the $2.49 billion total utility system losses. Oil, natural gas and communication facilities incur roughly 0.1% of all utility losses, which is a very small margin for three major utility systems.

Table 54: Utility System Losses – Central Level I

Utility System	Loss	% Total
Potable Water Facility	$151,810,000	6.10%
Potable Water Lines	$110,080,000	4.42%
Waste Water Facility	$1,767,560,000	71.02%
Waste Water Lines	$87,060,000	3.50%
Oil Facilities	$40,000	0.00%
Nautral Gas Facilities	$1,430,000	0.06%
Natural Gas Lines	$93,070,000	3.74%
Electric Systems	$276,130,000	11.10%
Communication	$1,530,000	0.06%
Total	**$2,488,710,000**	

6.1.2.6 Induced Damage

The scenario earthquake under investigation herein ignites 48 earthquakes and burns roughly 0.27 square miles. This burned area equates to less than 0.01% of the total regional area, however. Figure 77 compliments this data, illustrating the extent of fire demand in gallons of water per minute. Fire demand appears to be distributed randomly, not following attenuation trends as building damage does. HAZUS-MH estimates show that 82 people are displaced due to fires following the scenario earthquake and generate approximately $5.4 million in economic losses.

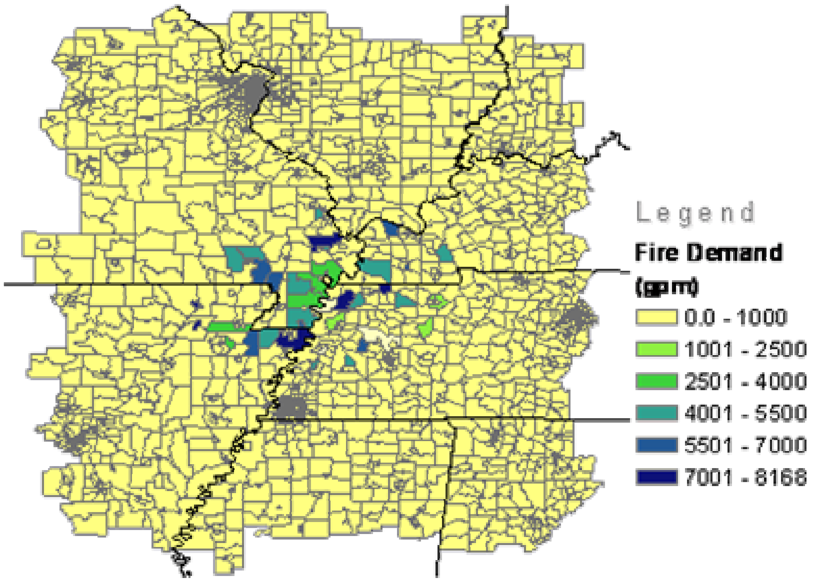


Figure 77: Fire Demand (gpm) – Central Level I

Damage estimates are used to determine debris generation across the study region. Most infrastructure damage occurs nearest the epicenter and thus most debris is generated in those census tracts. Approximately three million tons of debris are generated due to the scenario earthquake. About 1.7 tons are brick and wood, while the remaining 1.3 tons is from steel and concrete. Debris removal will require 120,000 truckloads across the region (See Figure 78).

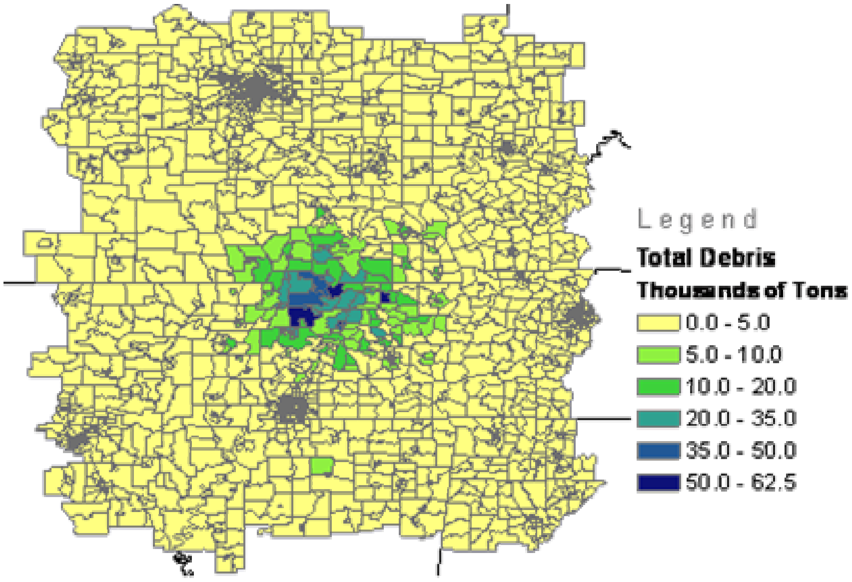


Figure 78: Total Debris (Thousands of Tons) - Central Level I

6.1.2.7 Social and Economic Losses

Estimates of displaced residents indicate that 5,192 households will require alternative housing due to uninhabitable homes. Of those displaced households approximately 1,554 people will require temporary housing (See Table 55). Missouri and Tennessee see the greatest number of displaced households and temporary housing needs. Alabama, Indiana and Mississippi have relatively no displaced residents, by comparison.

Table 55: Shelter Requirements – Central Level I

	Displaced Households	Temporary Housing
Alabama	0	0
Arkansas	335	101
Illinois	26	9
Indiana	1	0
Kentucky	212	63
Mississippi	3	1
Missouri	2,694	824
Tennessee	1,921	556
Total	***5,192***	***1,554***

The worst case for regional casualties occur at 2 PM, with 4,184 total casualties. Other casualty calculations indicate 3,963 at 2 AM and 3,953 at 5 PM. Table 56 shows the distribution of casualties by severity level and general occupancy type. Roughly 75% of all casualties are Level 1 minor injuries and only 5% are severe injuries and fatalities. Commercial buildings account for more than half of all casualties, with 2,264 casualties. Educational and single family homes incur 600 and 551 casualties, respectively.

Table 56: Casualties - 2 PM – Central Level I

	Level 1	**Level 2**	**Level 3**	**Level 4**
Commercial	1,808	342	39	75
Commuting	3	3	6	1
Educational	457	96	13	24
Hotels	6	1	0	0
Industrial	276	47	5	9
Other-Residential	346	60	5	10
Single Family	423	91	13	24
TOTAL	**3,319**	**640**	**81**	**143**

Direct building losses are quantified in Table 57 & Table 58 where capital and income losses are divided by state and general occupancy category, respectively. A total loss of $5.8 billion is incurred by regional buildings, with nearly half of that in Tennessee alone. Another 25% is lost in Missouri and the remaining value divided between the other six states. Additionally, nearly $3.2 billion is lost through damage to residential buildings, while another one-third is incurred by commercial buildings. Industrial and other buildings (government, educational and religion) comprise approximately 10% of all building losses.

Table 57: Direct Building Losses by State ($ thousands) – Central Level I

	Capital Losses					**Income Losses**				
	Structural Damage	**Non-Structural Damage**	**Contents Damage**	**Inventory Loss**	**Loss Ratio**	**Relocation Loss**	**Capital Related Loss**	**Wages Loss**	**Rental Income Loss**	**Total Loss**
Alabama	$2,921	$12,703	$5,675	$253	0.05	$48	$824	$1,160	$871	**$24,456**
Arkansas	$99,017	$270,332	$96,737	$4,104	0.57	$2,216	$24,072	$32,342	$31,164	**$559,984**
Illinois	$56,551	$139,248	$51,639	$1,180	0.44	$1,105	$14,147	$17,631	$15,164	**$296,666**
Indiana	$6,659	$16,821	$9,771	$811	0.05	$52	$715	$865	$926	**$36,620**
Kentucky	$101,410	$236,376	$82,173	$2,562	1.37	$2,354	$31,838	$44,338	$29,985	**$531,035**
Mississippi	$29,774	$77,678	$32,475	$2,207	0.26	$606	$10,781	$14,873	$8,734	**$177,128**
Missouri	$299,508	$794,739	$261,314	$10,262	2.14	$6,806	$55,627	$79,894	$86,928	**$1,595,078**
Tennessee	$433,991	$1,212,123	$433,082	$16,320	2.87	$10,409	$131,891	$184,473	$141,776	**$2,564,065**
TOTAL	***$1,029,830***	***$2,760,020***	***$972,866***	***$37,699***		***$23,596***	***$269,895***	***$375,578***	***$315,548***	***$5,785,032***

Transportation losses are greatest in Missouri followed by Tennessee with overall regional losses of over $456 million. Approximately one-third of all losses are attributed to highways and roughly another one-third to airport facilities. Railway, bus, ferry and airport facilities show the highest loss ratios, all of which are greater than four. These high loss ratios indicate significant portions of the region's dollar exposure has sustained damage and incurred large economic losses (See Table 59 & Table 60).

Table 58: Direct Building Losses by General Occupancy Class ($ millions) – Central Level I

		Single Family	Other Residential	Commercial	Industrial	Others	TOTAL
Income Losses	**Wage**	$0.00	$13.31	$329.65	$16.97	$15.65	**$375.58**
	Capital-Related	$0.00	$5.89	$248.46	$10.62	$4.93	**$269.90**
	Rental	$70.22	$76.61	$144.75	$6.54	$5.95	**$304.07**
	Relocation	$7.53	$3.36	$10.04	$0.57	$2.10	**$23.60**
	SUBTOTAL	**$77.75**	**$99.17**	**$732.90**	**$34.70**	**$28.63**	**$973.15**
Capital Stock Losses	**Structural**	$326.08	$238.05	$319.90	$67.42	$78.39	**$1,029.84**
	Non-Structural	$1,214.36	$680.62	$604.64	$131.04	$129.36	**$2,760.02**
	Content	$429.54	$127.52	$271.99	$79.62	$64.20	**$972.87**
	Inventory	$0.00	$0.00	$13.56	$20.28	$3.85	**$37.69**
	SUBTOTAL	**$1,969.98**	**$1,046.19**	**$1,210.09**	**$298.36**	**$275.80**	**$4,800.42**
	TOTAL	***$2,047.73***	***$1,145.36***	***$1,942.99***	***$333.06***	***$304.43***	***$5,773.57***

Table 59: Direct Transportation Losses by State ($ thousands) – Central Level I

	Transportation							
	Highway	Railway	Light Rail	Bus Facility	Ports	Ferries	Airports	Total
Alabama	$1,294	$297	$0	$37	$1,375	$0	$1,198	**$4,202**
Arkansas	$28,403	$3,342	$0	$207	$6,036	$0	$26,056	**$64,044**
Illinois	$13,298	$3,096	$0	$595	$8,429	$2,420	$20,183	**$48,021**
Indiana	$247	$832	$0	$18	$1,864	$0	$3,948	**$6,909**
Kentucky	$9,734	$6,142	$0	$243	$19,245	$1,068	$11,927	**$48,359**
Mississippi	$6,144	$241	$0	$96	$1,102	$0	$7,731	**$15,313**
Missouri	$64,881	$15,711	$0	$2,212	$29,293	$1,123	$46,461	**$159,680**
Tennessee	$53,070	$9,515	$0	$1,028	$16,184	$959	$29,429	**$110,185**
TOTAL	***$177,071***	***$39,176***	***$0***	***$4,435***	***$83,529***	***$5,570***	***$146,932***	***$456,713***

Table 60: Direct Transportation Losses by Subsystem Components – Central Level I

	Inventory Value	Economic Loss	Loss Ratio
Highway Bridges	$25,505,730,000	$177,070,000	0.69%
Railway Bridges	$53,160,000	$50,000	0.09%
Railway Facilities	$830,860,000	$39,130,000	4.71%
Bus Facilities	$90,310,000	$4,440,000	4.92%
Ferry Facilities	$5,570,000	$5,570,000	100.00%
Port Facilities	$1,413,120,000	$83,530,000	5.91%
Airport Facilities	$3,366,410,000	$146,930,000	4.36%

The final economic loss category is utility losses. Loss values are delineated by state and general occupancy in Table 61 & Table 62, respectively. A total of $2.5 billion in economic losses is incurred by utility systems, with nearly half of that occurring in Missouri alone. Tennessee shows nearly 25% of all utility losses with the remaining six states experiencing lesser losses. Alabama and Indiana show the smallest losses by far, at $11 million each.

Table 61: Utility System Losses by State ($ thousands) – Central Level I

	Utility Systems						
	Potable Water	Waste Water	Oil Systems	Natural Gas	Electric Power	Communication	Total
Alabama	$2,483	$5,096	$0	$1,812	$2,320	$10	**$11,720**
Arkansas	$23,059	$244,505	$7	$13,432	$39,815	$189	**$321,007**
Illinois	$26,679	$181,094	$2	$8,053	$21,730	$109	**$237,667**
Indiana	$2,105	$5,447	$1	$1,214	$2,371	$8	**$11,146**
Kentucky	$23,280	$140,140	$0	$7,573	$23,825	$167	**$194,985**
Mississippi	$6,191	$36,390	$0	$4,759	$4,651	$41	**$52,032**
Missouri	$122,062	$798,927	$2	$31,350	$154,167	$507	**$1,107,017**
Tennessee	$56,026	$443,019	$31	$26,299	$27,255	$499	**$553,130**
TOTAL	***$261,885***	***$1,854,618***	***$44***	***$94,493***	***$276,134***	***$1,530***	**$2,488,704**

Table 62: Utility System Losses by Subsystem Component – Central Level I

	Inventory Value	Economic Loss	Loss Ratio
Potable Water Facilities	$8,314,300,000	$151,810,000	1.83%
Potable Water Distribution Lines	$10,011,200,000	$110,080,000	1.10%
Waste Water Facilities	$108,128,400,000	$1,767,560,000	1.63%
Waste Water Distribution Lines	$6,006,700,000	$87,060,000	1.45%
Natural Gas Facilities	$117,100,000	$1,430,000	1.22%
Natural Gas Distribution Lines	$4,004,500,000	$93,070,000	2.32%
Oil Facilities	$4,800,000	$40,000	0.83%
Electric Power Facilities	$17,087,400,000	$276,130,000	1.62%
Communication Facilities	$89,600,000	$1,530,000	1.71%

Over 75% of all utility losses are incurred by waste water systems. Oil and communication systems show $0.04 and $1.5 millions, respectively. Economic losses are experienced by waste water systems primarily. Another 10% in attributed to potable water systems, while oil systems see minimal inventory losses around $40 million.

Total regional direct economic losses total $8.7 billion. Building losses comprise more than half of all losses, while utility and transportation losses account for 28% and 5%, respectively. These values are reflected in Table 63. Further direct economic losses are detailed by state as well. As with various direct economic loss categories, Missouri and Tennessee incur the greatest total direct economic losses at $2.8 and $3.2 billion, or 33% and 36% of regional losses, respectively. Arkansas sees 11% of all losses at $945 million. Again, Alabama and Indiana show the lowest loss values of all study region states.

Finally, induced losses resulting from business interruption is detailed in Table 64. In the first year following the scenario earthquake nearly 3.5 million jobs are added for recovery staff and monetary losses are roughly $11.5 billion. The region begins to recover in the second year, despite the fact that losses are still accruing. By the fourth year following the earthquake the region begins to see positive income again. Also, employment increases level out as fewer and fewer regional recovery and rebuilding jobs are required.

Table 63: Total Direct Economic Losses – Central Level I

	Total Loss ($ Thousands)
Alabama	$40,378
Arkansas	$945,035
Illinois	$582,354
Indiana	$54,674
Kentucky	$774,380
Mississippi	$244,473
Missouri	$2,861,775
Tennessee	$3,227,379

	Total Loss ($ Billions)
Buildings	$5.8
Transporation	$0.5
Utilities	$2.5
TOTAL	**$8.7**

Table 64: Induced Economic Losses without Aid – Central Level I

	Loss	Total	%
First Year	Employment Impact	3,535,300	118.71
	Income Impact	11,468	8.09
Second Year	Employment Impact	1,229,631	41.29
	Income Impact	5,814	4.10
Third Year	Employment Impact	27,917	0.94
	Income Impact	1,441	1.02
Fourth Year	Employment Impact	1,574	0.05
	Income Impact	-87	-0.06
Fifth Year	Employment Impact	90	0.00
	Income Impact	-173	-0.12
Years 6 to 15	Employment Impact	5	0.00
	Income Impact	-178	-0.13

6.1.3 Southwest Epicenter

6.1.3.1 Ground Motion

The southwest epicenter is located in northeastern Arkansas as is shown previously (See Figure 21). This positioning represents an earthquake occurring along the southwest extension of the New Madrid fault. It is expected that this epicenter location will provide worst-case scenario data for southern states within the study region;

Alabama, Mississippi and Arkansas. Ground motion inputs are shown in Figure 79-Figure 82 for this scenario earthquake. Peak ground acceleration is maximum at the epicenter with a value at 1.05*g*. This is by far the greatest PGA of all the epicenters. The PGA map, as well as other ground motion maps, illustrate the moderate ground shaking values at the western and southern boundaries of the study region. PGA values of nearly 0.2*g* exist at the boundary, indicating that further attenuation in these locations is warranted by increasing the study region size. Additionally, the northern third of the

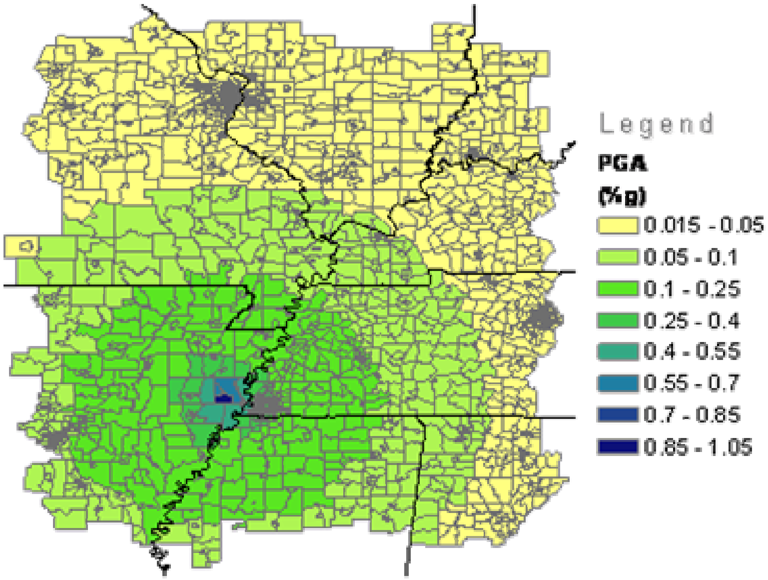


Figure 79: Southwest Epicenter PGA (g) – SW Level I

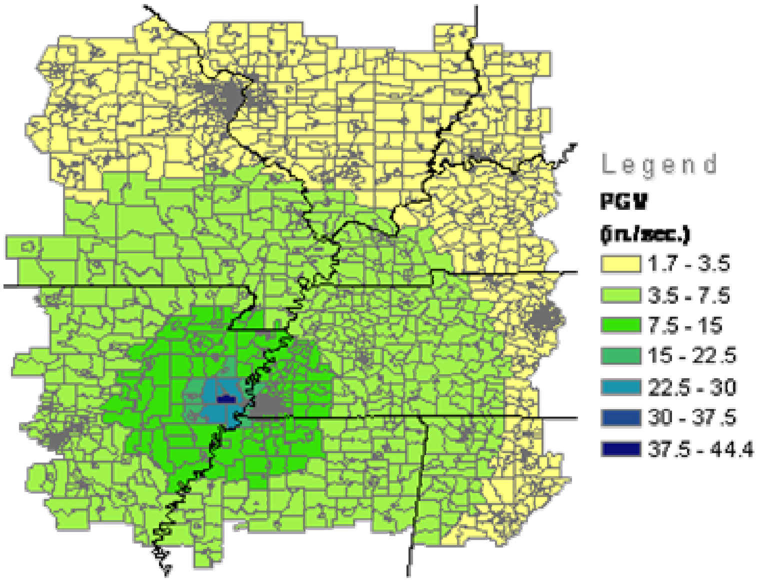


Figure 80: Southwest Epicenter PGV (in./sec.) – SW Level I

region does not experience significant shaking, less than 0.05*g* PGA, as well as short- and long-period spectral acceleration responses. Peak ground velocity reaches a maximum of over 44 in./sec., while short- and long-period spectral accelerations reach 2.62*g* and 1.2*g* maximum values, respectively. As with PGA, these ground motion responses are the greatest of all three epicenters.

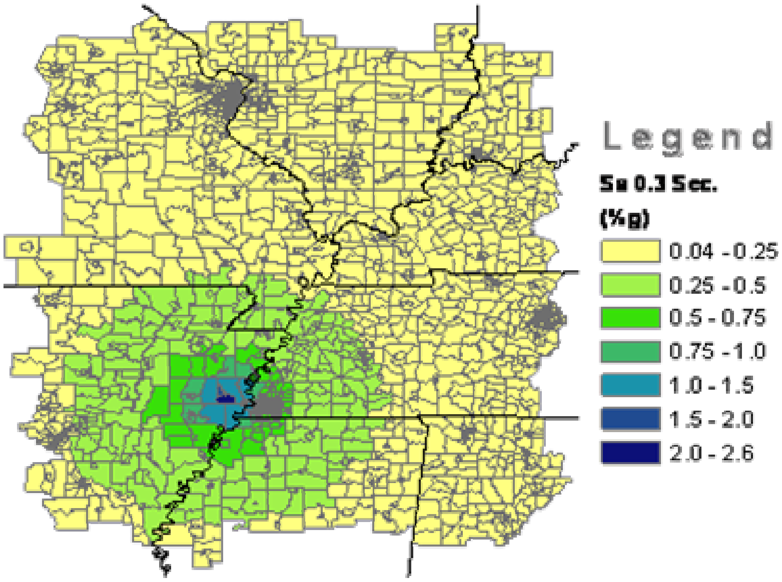


Figure 81: Southwest Epicenter S_a 0.3 Sec. (g) – SW Level I

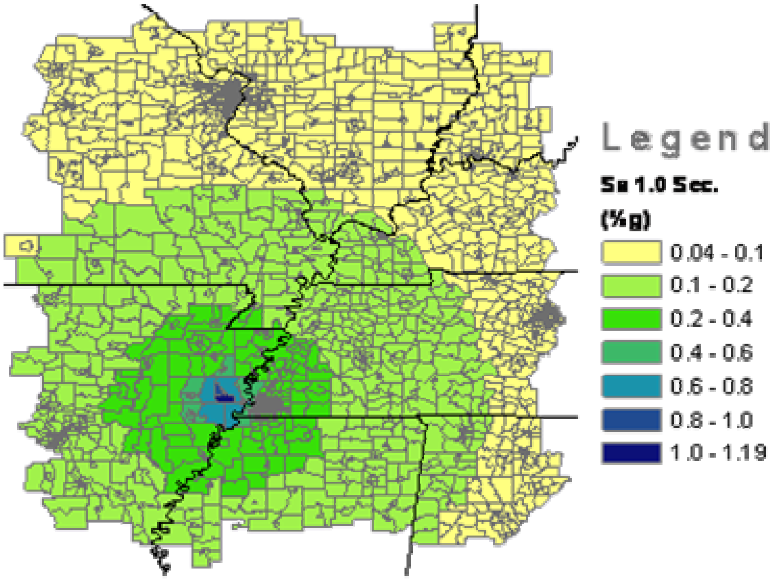


Figure 82: Southwest Epicenter S_a 1.0 Sec. (g) – SW Level I

Spectral displacements for this scenario earthquake are also illustrated herein; see Figure 83 & Figure 84. Short-period spectral displacements are greatest in the census tract where the earthquake occurs, whereas long-period displacements appear to reduce over a greater distance, approximately 20 km. Short-period maximum displacements reach nearly five inches, though more common regional values are between 0.25- and 1.5-inches. The greatest long-period displacement far exceeds the short-period maximum at nearly 7.5-inches. The remainder of the region, however; experiences more typical long-period displacements between 0.5- and 1.75-inches.

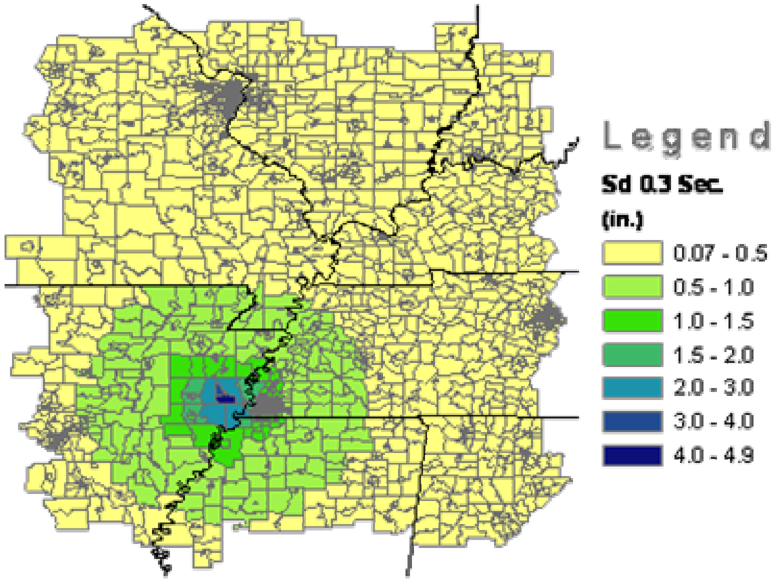


Figure 83: Southwest Epicenter S_d 0.3 Sec. (in.) – SW Level I

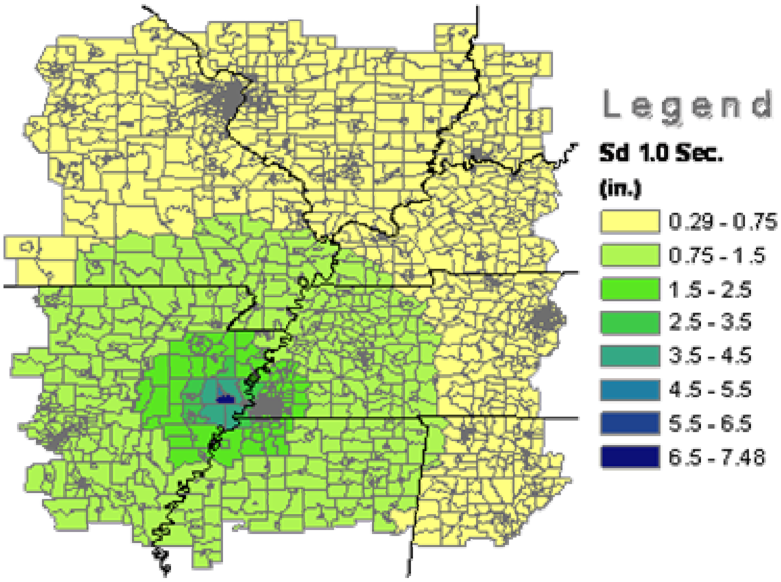


Figure 84: Southwest Epicenter S_d 1.0 Sec. (in.) – SW Level I

6.1.3.2 General Building Stock

Structural damage for an earthquake at the southwest epicenter appears to be greatest for light wood frame buildings. As shown in Figure 85 census tracts within 75 km of the epicenter are more than 55% likely to experience at least moderate damage. Unreinforced masonry buildings show similar trends, though the region of lesser damage state probabilities (10%-40% of damage state exceedance) is much more condensed. This mid-range of probabilities stretches for nearly another 75 km for building type W1. The damage state probability distributions exhibited by light wood frames apply to unreinforced masonry buildings and are completely opposite the behavior shown by mobile homes. High probabilities of meeting or exceeding moderate damage exist within the census tracts immediately surrounding the epicenter only. Previous epicenters indicated that mobile homes are very likely to sustain at least moderate damage, though the southwest epicenter shows that mobile homes are not likely to incur damage outside the small region around the epicenter. Additionally, there is not an extensive area with moderate or low probabilities of reaching this damage state. All tracts with at least 10% probability of moderate damage or greater are within 50 km of the epicenter, as shown in Figure 86 & Figure 87.

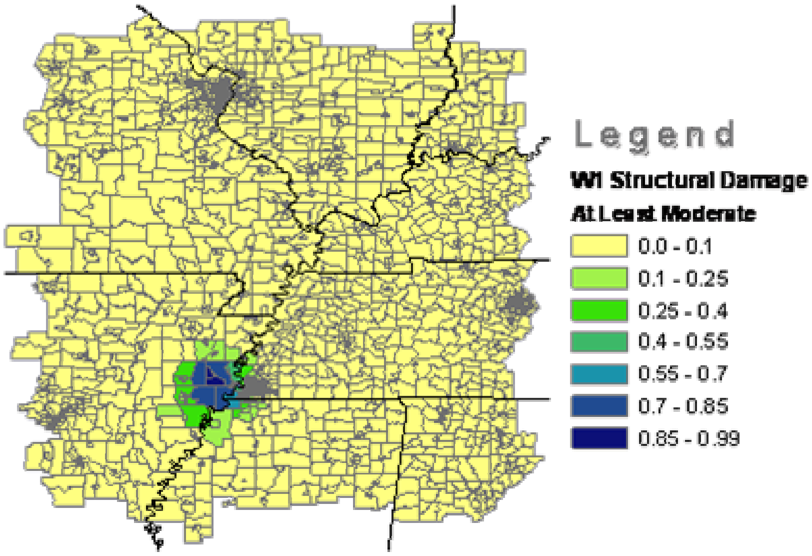


Figure 85: At Least Moderate Damage - W1 – SW Level I

Damage to non-structural components follows behavioral trends for damage state exceedance presented for structural damage. This means that mobile homes experience the same extents of non-structural drift- and acceleration-controlled damage as structural damage, which occurs over an extremely confined region. Figure 88 & Figure 89, illustrate the extents of damage state probabilities for acceleration- and drift-controlled components of low-rise unreinforced masonry buildings. Acceleration sensitive components show the pattern of damage state probabilities exhibited in the analysis of previous epicenters. A small area in the immediate vicinity of the epicenter experiences high probabilities of damage state exceedance, while moderate to low probabilities extend for over 100 km. Drift-sensitive components show opposing behavior, with a larger area of high damage state likelihoods for at least moderate damage and a much shorter distance over which these probabilities decrease rapidly. The non-structural response of light wood frame buildings is similar to URML buildings with regard to source-to-site distance and damage state probability and thus are not pictured here.

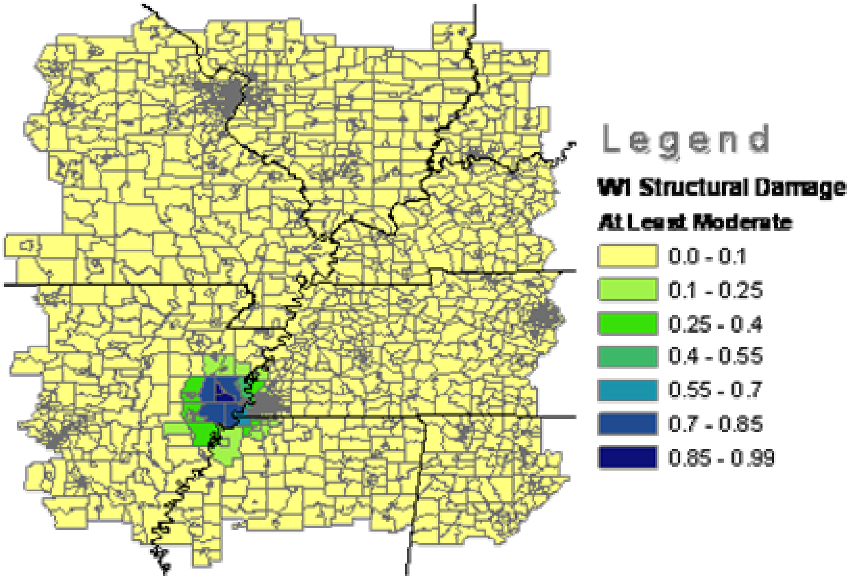


Figure 86: At Least Moderate Damage-URML – SW Level I

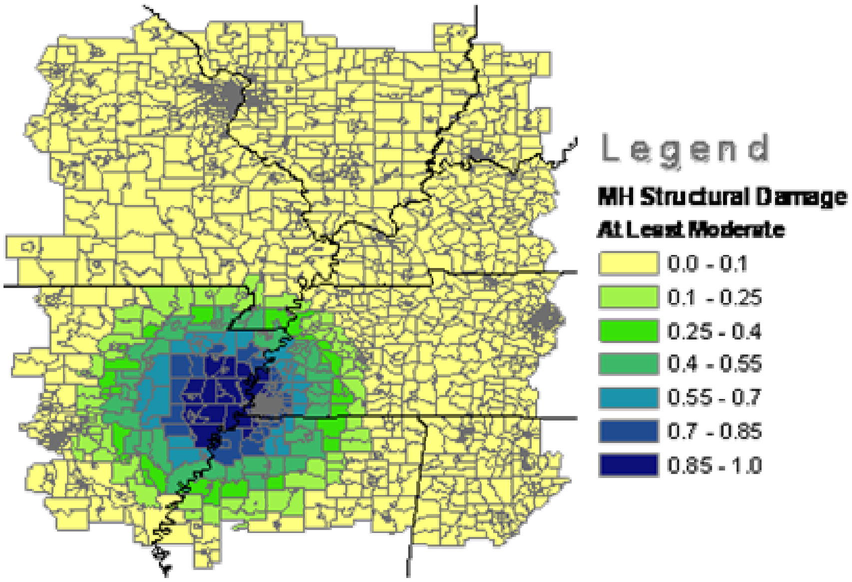


Figure 87: At Least Moderate Damage - MH – SW Level I

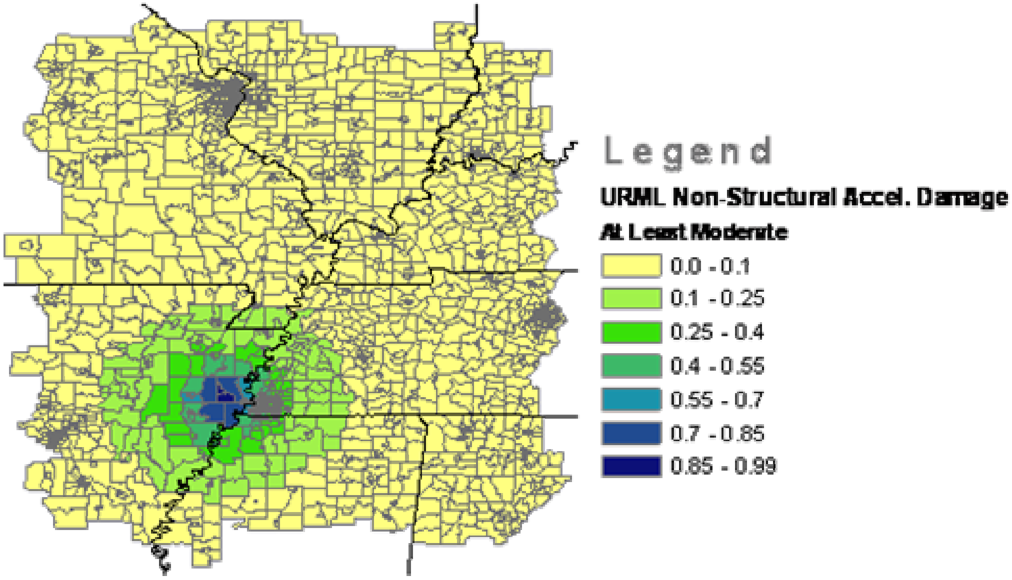


Figure 88: Non-Structural Acceleration-URML – SW Level I

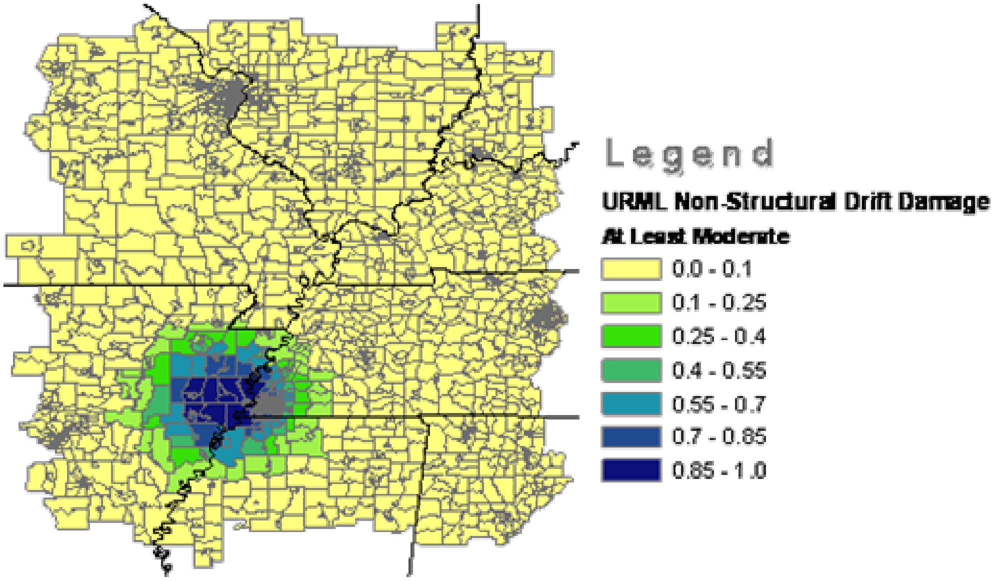


Figure 89: Non-Structural Drift - URML – SW Level I

Damage state probabilities for the southwest scenario earthquake lead to the building damage estimates listed in Table 65. Light wood frames fare the best of the three primary building types. Only 10% of all buildings incur some form of damage and less than 0.01% are predicted to collapse. There are over 2.75 million light wood frame buildings in this study region and only 132 buildings are estimated to collapse, while over 5,700 URMs and mobile homes are estimated to experience the same form of damage, despite the lesser inventory of these two building types. Unreinforced masonry buildings exhibit roughly 15% damage rate. Over 40% of all damaged URMs incur only slight damage, or minor cracking. Over 7% of all damaged buildings collapse, though this equates to 1% of all URMs collapsing and this percentage is over 100 times greater than light wood frames. This trend is also shown with the central epicenter.

Table 65: Building Damage by Count and Seismic Code Level – SW Level I

	Light Wood Frame				
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Buildings	273,453	167,221	45,984	2,031	126
Total Low Code Buildings	2,192,669	59,995	12,437	542	6
Total Buildings	**2466122**	**227216**	**58421**	**2573**	**132**
		Total Number of Building Type:			2754464
%Total Buildings	***89.532%***	***8.249%***	***2.121%***	***0.093%***	***0.005%***

	Unreinforced Masonry				
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Buildings	21724	9110	16019	10164	2641
Total Low Code Buildings	169733	6150	2244	549	74
Total Pre-Code Buildings	253770	16064	8517	5627	3019
Total Buildings	**445227**	**31324**	**26780**	**16340**	**5734**
		Total Number of Building Type:			525405
%Total Buildings	***84.740%***	***5.962%***	***5.097%***	***3.110%***	***1.091%***

	Mobile Homes				
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Buildings	19054	9202	12136	4362	635
Total Low Code Buildings	144877	16423	8717	807	7
Total Pre-Code Buildings	169596	36416	47399	12840	2182
Total Buildings	**333527**	**62041**	**68252**	**18009**	**2824**
		Total Number of Building Type:			484653
%Total Buildings	***68.818%***	***12.801%***	***14.083%***	***3.716%***	***0.583%***

While the damage probability map for mobile homes showed very few census tracts likely to experience at least moderate damage, the damaged building counts presented here show that over 30% of the entire mobile home inventory incurs damage, while nearly 60% of damaged buildings fall into the 'moderate or greater' category. With over 89,000 mobile homes showing at least moderate damage it is relevant to determine the locations of this extensive damage. Figure 90 illustrates the number of mobile homes incurring moderate damage. Some of the tracts nearest the epicenter do not show any moderate damage due to the extensive or complete nature of damage there. Moderate damage, however; extends far beyond the area shown to have greater than 10% likelihood of experiencing at least moderate damage.

The building count damage distributions with regard to damage state are not as clearly reflected in square footage damaged as was the case with previous epicenters. Table 66 delineates the square footage in each damage state by seismic code level. Damage to regional building square footage shows roughly the same percentages as the regional building count.

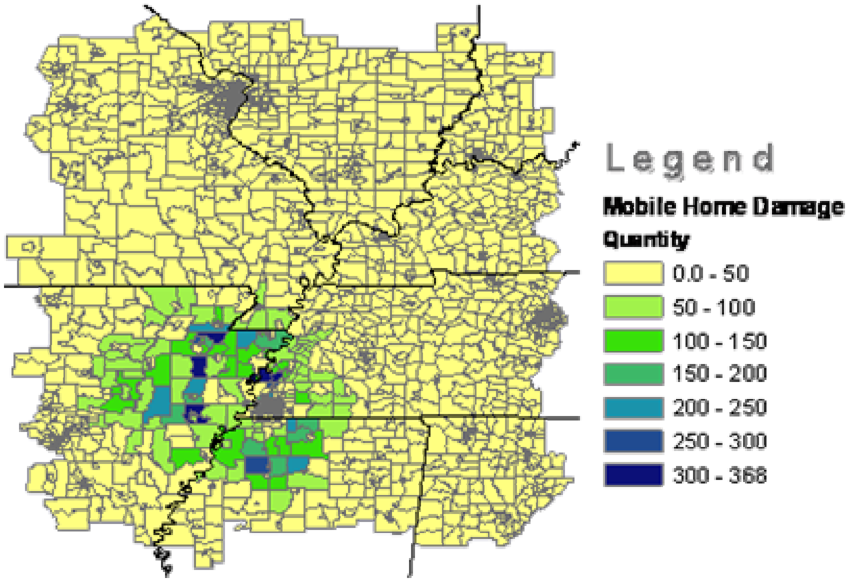


Figure 90: Number of Mobile Homes with Moderate Damage – SW Level I

Table 66: Building Damage by Square Footage – SW Level I

	Light Wood Frame				
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Square Footage	476,414,670	300,933,900	84,268,010	3,648,860	234,550
Total Low Code Square Footage	3,887,406,200	102,583,480	21,213,750	925,510	11,620
Total Square Footage	**4,363,820,870**	**403,517,380**	**105,481,760**	**4,574,370**	**246,170**
		Total Number of Square Footage Type:			4,877,640,550
%Total Square Footage	***89.466%***	***8.273%***	***2.163%***	***0.094%***	***0.005%***
	Unreinforced Masonry				
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Square Footage	50326280	23786610	47580240	32012490	8137570
Total Low Code Square Footage	393863410	15177610	5622220	1449920	199370
Total Pre-Code Square Footage	692411900	48469980	26433340	17876700	9604960
Total Square Footage	**1,136,601,590**	**87,434,200**	**79,635,800**	**51,339,110**	**17,941,900**
		Total Number of Square Footage Type:			1,372,952,600
%Total Square Footage	***82.785%***	***6.368%***	***5.800%***	***3.739%***	***1.307%***
	Mobile Homes				
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Square Footage	20930240	10140200	13273470	4764250	698600
Total Low Code Square Footage	157691020	17870770	9491550	891820	10950
Total Pre-Code Square Footage	185158240	39565570	51528500	13939270	2414410
Total Square Footage	**363,779,500**	**67,576,540**	**74,293,520**	**19,595,340**	**3,123,960**
		Total Number of Square Footage Type:			528,368,860
%Total Square Footage	***68.850%***	***12.790%***	***14.061%***	***3.709%***	***0.591%***

Damage characterizations by state are displayed in Table 67. The southern epicenter shifts extensive and complete damage to the southern states; Mississippi, Arkansas, and more in Alabama, than in previous scenarios. Northern states such as Illinois and Indiana experience relatively minimal damage when compared to the northeast of central epicenters. This regional distribution of damage is intuitive, however; based on the location of the epicenter.

Table 67: Building Damage by Count and State – SW Level I

	Low-Code					
	None	Slight	Moderate	Extensive	Collapse	Total
Alabama	204,691	778	27	0	0	**205,496**
Arkansas	310,168	28,939	5,287	320	10	**344,724**
Illinois	332,773	224	7	0	0	**333,005**
Indiana	128,435	15	0	0	0	**128,450**
Kentucky	190,766	596	23	0	0	**191,385**
Mississippi	174,531	39,693	16,512	1,582	88	**232,406**
Missouri	668,430	979	56	0	0	**669,465**
Tennessee	505,384	12,108	1,884	90	1	**519,466**
Code Total	**2,515,177**	**83,331**	**23,797**	**1,992**	**99**	**2,624,396**
	Moderate-Code					
	None	Slight	Moderate	Extensive	Collapse	Total
Alabama	0	0	0	0	0	**0**
Arkansas	73,972	37,670	25,049	6,897	1,793	**145,380**
Illinois	10,911	127	7	0	0	**11,045**
Indiana	0	0	0	0	0	**0**
Kentucky	9,776	236	17	0	0	**10,028**
Mississippi	0	0	0	0	0	**0**
Missouri	88,704	6,147	1,196	37	0	**96,083**
Tennessee	132,688	142,630	49,426	10,091	1,663	**336,498**
Code Total	**316,049**	**186,809**	**75,695**	**17,024**	**3,457**	**599,035**
Region Total	**2,831,227**	**270,141**	**99,492**	**19,017**	**3,556**	**3,223,431**
% Region Total	***87.833%***	***8.381%***	***3.087%***	***0.590%***	***0.110%***	

Table 68: Building Damage by General Occupancy – SW Level I

	None		Slight		Moderate		Extensive		Complete	
	Count	%	Count	%	Count	%	Count	%	Count	%
Agriculture	2,113	0.06%	42	0.01%	35	0.02%	13	0.03%	2	0.02%
Commercial	28,550	0.87%	3,077	0.95%	3,169	2.01%	1,489	3.86%	496	5.39%
Education	242	0.01%	26	0.01%	21	0.01%	7	0.02%	3	0.03%
Government	1,427	0.04%	142	0.04%	115	0.07%	37	0.10%	13	0.14%
Industrial	4,251	0.13%	601	0.19%	806	0.51%	370	0.96%	91	0.99%
Other Residential	450,930	13.75%	71,962	22.19%	73,048	46.37%	19,749	51.25%	3,431	37.29%
Religion	2,196	0.07%	202	0.06%	176	0.11%	91	0.24%	33	0.36%
Single Family	2,790,733	85.07%	248,316	76.55%	80,165	50.89%	16,775	43.54%	5,131	55.77%
TOTAL	**3,280,442**		**324,368**		**157,535**		**38,531**		**9,200**	

Damage is also categorized by general occupancy and appears in Table 68. Residential buildings comprise nearly 99% of all undamaged buildings, while only accounting for 92% of all completely damaged buildings. A large number of commercial building also see significant collapse rates, or over 5% of all commercial buildings. This is in contrast to agricultural, religious, and educational buildings which show a collapse rate much less than 1%. Industrial buildings appear to undergo extensive amounts of slight and moderate damage with 601 and 806 buildings in those damage states, respectively. This equates to 14% of all industrial buildings showing slight damage and 19% showing moderate damage.

6.1.3.3 Essential Facilities

Essential facilities damage state probability distributions for moderate, extensive and complete damage mimic the trends shown by the general building stock, in particular unreinforced masonry buildings. Figure 91 illustrates the likelihood of at least moderate damage to regional schools. The highest damage state probabilities, greater than 85%, occur in or near Memphis, Tennessee, subjecting a major city to intense shaking which damages the dense urban fabric of the city. As shown in this figure all the schools in the Memphis area are likely to sustain heavy damage. The distribution of damage for schools is replicated, without major deviation, for the remaining essential facility types. The location of Memphis in relation to the epicenter is of the utmost concern, as all essential facilities in that urban area are likely to experience extensive or complete damage, rendering them useless in an emergency.

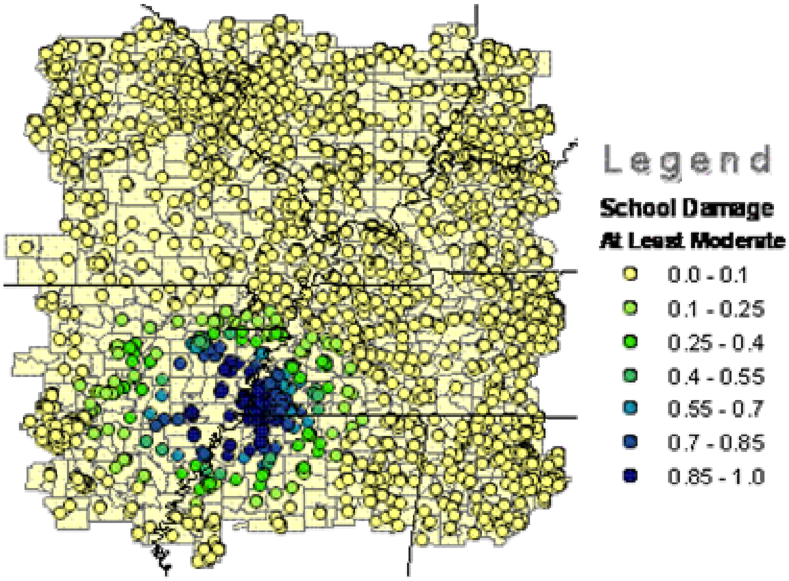


Figure 91: At Least Moderate Damage - Schools – SW Level I

The damage of essential facilities, particularly in Memphis, is reflected in the functionalities for each facility type. Table 69 details the functionality of each facility type at six periods after the earthquake. Hospitals and police stations exhibit the lowest functionalities the day after the earthquake, which is a major concern. With decreased medical and security aid fewer injured persons are able to receive the care they need and a reduced police force may not be able to maintain order in the chaotic aftermath of a catastrophe. Essential facilities do not recover as quickly from the southwest scenario earthquake as the region does from the previous two earthquakes. Only after a month of recovery efforts are 90% of all essential facilities functional. With the majority of the non-operational buildings nearest the epicenter this means Memphis and its surrounding areas are likely to go without these services for an extended period of time.

Table 69: Essential Facilities Functionalities – SW Level I

	Hospitals		Fire Stations		Police Stations		Schools	
	308 Total Strucutres		1465 Total Strucutres		1207 Total Strucutres		4695 Total Strucutres	
	No. Functional	% of Total Functional	No. Functional	% of Total Functional	No. Functional	% of Total Functional	No. Functional	% of Total Functional
Day 1	258	83.77%	1253	85.53%	1006	83.35%	4028	85.79%
Day 3	259	84.09%	1254	85.60%	1008	83.51%	4036	85.96%
Day 7	275	89.29%	1356	92.56%	1099	91.05%	4231	90.12%
Day 14	275	89.29%	1356	92.56%	1099	91.05%	4234	90.18%
Day 30	303	98.38%	1426	97.34%	1153	95.53%	4513	96.12%
Day 90	307	99.68%	1450	98.98%	1195	99.01%	4660	99.25%

Essential facilities damage is depicted in Table 70 by facility type. Schools show the greatest amount of damage occurrences at each damage level. This equates to roughly 10% and less than 1% of all schools experiencing at least moderate and complete damage, respectively. As with the previous scenarios no hospitals experience complete damage, nor do EOCs. Only ten total essential facilities collapse and these lie nearest the source of seismic activity.

Table 70: Essential Facilities Damage - SW Level I

		No. of Facilities	
Classification	Total	Moderate Damage >50%	Complete Damage >50%
Hospitals	308	33	0
Schools	4,695	461	4
EOCs	92	4	0
Police Stations	1,207	108	2
Fire Stations	1,465	109	4

6.1.3.4 Transportation Systems

Highway bridge damage is not confined to areas near the epicenter, as building damage appears to be. Bridges at least 20% likely to experience moderate damage or greater are located as far as 200 km from the epicenter. These probabilities are seen on bridges to the north and east of the southwest scenario epicenter. Despite the large number of bridges and expansive area over which bridges are likely to incur damage, only 52 bridges are more than 50% likely to collapse all of which are located within 30 km of the epicenter. Further evidence to this is seen through regional bridge functionalities. Table 71 quantifies the operational highway bridges throughout the region. While over 98% of all bridges are functional the day after the earthquake there are still 376 bridges that are not operational. These bridges are located within 75 km of the epicenter, which encompasses Memphis, Tennessee. The majority of bridges in that city will not be functioning immediately after the earthquake which will hinder the evacuation of victims and the movement of supplies and aid into the heavily damaged city. This damage equates to over $310 million in economic losses, which is significantly higher than the two previous epicenters.

Damage to regional transportation facilities is quantified in Table 72 by facility type. At least moderate damage occurs to only 420 total transportation facilities which equates to just over 1% of all 32,500 facilities. Railway facilities show roughly 5% occurrence of at least moderate damage, which is much greater than other facility types. Complete damage is much less likely, with only 12 total facilities experiencing this type of damage.

Table 71: Highway Bridge Functionalities – SW Level I

Highway Bridge Fuctionality		
Time	No. Functional	% Total Functional
Day 1	29938	98.76%
Day 3	30021	99.03%
Day 7	30119	99.36%
Day 14	30130	99.39%
Day 30	30148	99.45%
Day 90	30231	99.73%

Table 72: Transportation System Damage - SW Level I

	Region Total	At Least Moderate Damage	Complete Damage
Highway Bridges	30,314	371	7
Railway Bridges	425	0	0
Railway Facilities	393	20	0
Bus Facilities	84	1	0
Ferry Facilities	5	5	5
Port Facilities	691	17	0
Airport Facilities	637	6	0

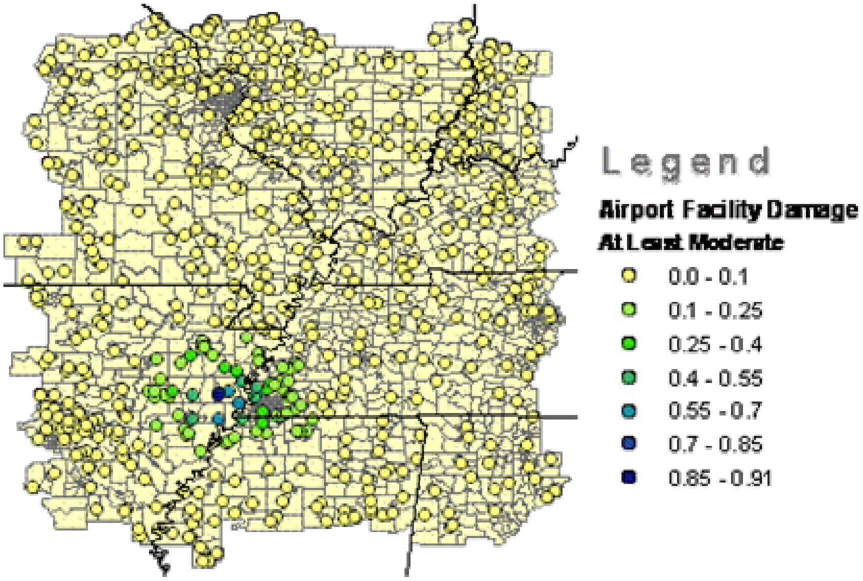


Figure 92: At Least Moderate Damage - Airports – SW Level I

Damage to railway bridges and facilities occurs only to the several inventory items in and around Memphis, though these types of transportation inventory are densely packed within urban Memphis. Railway bridges incur only $150,000 in losses, however; railways facilities account for nearly $47.3 million in economic losses. Distribution patterns for at least moderate damage for all transportation facilities are similar to the damage seen in Figure 92 for airport facilities. All airports more than 25% likely to experience moderate damage or greater are confined to within 50 km of the epicenter. Trends like this one hold true for bus, railway and port facilities. Losses associated with this damage reach nearly $575 million. Related losses include bus facility losses at nearly $3.43 million, port facilities at $70.5 million and ferry facilities at $5.57 million, which is true of all epicenters.

6.1.3.5 Utility Systems

Utility facilities, like all other facilities and buildings, experience significant damage in and around the Memphis area. The large urban population places high demands on all utilities, thus requiring more facilities and distribution lines than the average Midwestern community. Damage state probabilities for at least moderate damage are similar for all facilities and are represented by the damage patterns shown in Figure 93 for communications facilities. Damage probabilities are substantial to the northwest. Further utility facilities damage is characterized in Table 73. Numerous waste water facilities also experience moderate damage. It is important to note, though, that no utility facilities collapse which is reflected in the functionalities of these facilities.

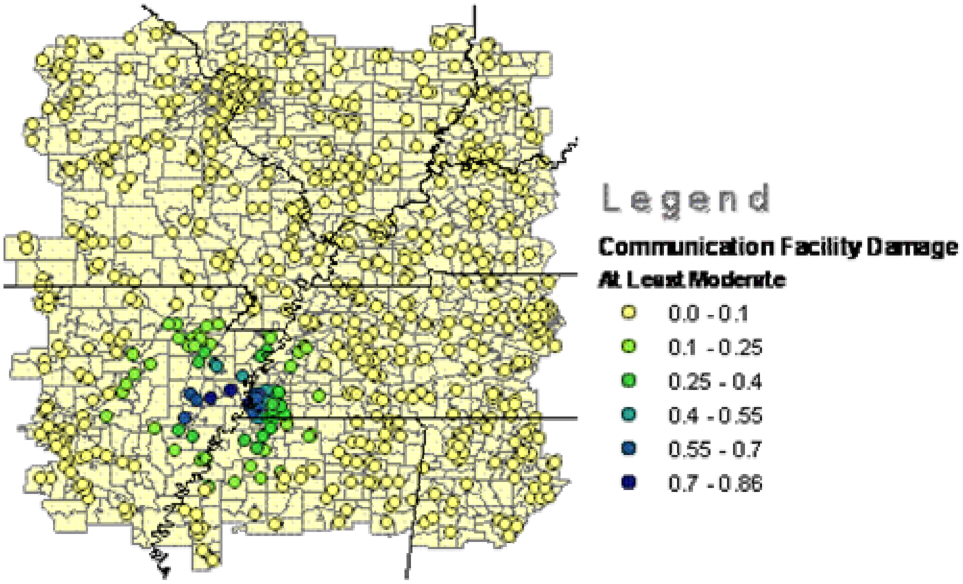


Figure 93: Communication Facilities - At Least Moderate Damage – SW Level I

Table 73: Utility Facilities Damage and Functionalities – SW Level I

	Region Total	At Least Moderate Damage	Complete Damage	With > 50% Functionality Day 1	With > 50% Functionality Day 7
Potable Water	249	1	0	248	249
Waste Water	1,646	31	0	1,568	1,643
Natural Gas	114	0	0	114	114
Oil	49	8	0	40	49
Electric Power	158	5	0	152	158
Communications	940	21	0	935	940

The previous table, in addition to Table 74, quantify the facilities that are operational at various intervals after an earthquake. As with the two previous epicenters, waste water facilities suffer the greatest functional loss immediately after an earthquake. More than 5% of all waste water facilities are not in operation immediately after the southwest scenario earthquake. The loss of oil facilities functionalities is uncommon of the previous two analysis cases. Only 81%, or 40 facilities, are functional the day after the earthquake. While these facilities recover quickly the initial level of damage is unusual based on previous earthquake analyses.

Table 74: Utility Systems Functionalities – SW Level I

	Utility Facilities Functionality						
	Day 1	**Day 3**	**Day 7**	**Day 14**	**Day 30**	**Day 90**	**Total**
Potable Water	248	249	249	249	249	249	**249**
Waste Water	1568	1631	1643	1643	1643	1646	**1646**
Natural Gas	114	114	114	114	114	114	**114**
Oil Systems	40	49	49	49	49	49	**49**
Electric Power	152	158	158	158	158	158	**158**
Communication	935	940	940	940	940	940	**940**

Service disruptions and distribution network damage also impact the functionality of utility systems. Water, oil and gas pipelines experience damage which is characterized by the amount of breaks and leaks in Table 75. As with the previous epicenters, potable water lines experience the greatest number of leaks and breaks at 25,727 and 6,932, respectively. Natural gas lines have the highest leak and break rates at 0.109 leaks/km and 0.027 breaks/km. The lowest rates belong to potable water system pipelines. Additional service disruptions for potable water and electricity are shown in Table 76. The day after the earthquake 4.2% of households are without potable water while 3.0% are without electricity. After 90 days all households have potable water service restored while 182 households are still without electricity. Long durations without these utilities, however; increases the number of displaced residents as they are not able to use their homes without critical services.

Table 75: Pipeline Damage – SW Level I

	Pipeline Length	Number of Leaks	Number of Breaks
Potable Water	500,560	25,727	6,432
Waste Water	300,336	20,347	5,087
Natural Gas	200,224	21,751	5,438
Oil	0	0	0

Table 76: Potable Water and Electricity Service Disruptions – SW Level I

		No. of Households without Service				
	Total No. Households	Day 1	Day 3	Day 7	Day 30	Day 90
Potable Water	4,236,197	179,530	151,206	110,354	9,926	0
Electric Power		128,802	66,976	19,696	2,715	182

Table 77: Utility System Losses – SW Level I

Utility System	Loss	% Total
Potable Water Facility	$57,880,000	2.85%
Potable Water Lines	$115,770,000	5.69%
Waste Water Facility	$1,448,670,000	71.25%
Waste Water Lines	$91,560,000	4.50%
Oil Facilities	$180,000	0.01%
Nautral Gas Facilities	$1,090,000	0.05%
Natural Gas Lines	$97,880,000	4.81%
Electric Systems	$218,610,000	10.75%
Communication	$1,460,000	0.07%
Total	**$2,033,100,000**	

Finally, utility system losses are determined by economic loss values for each subsystem. Waste water system experience the greatest loss at over $1.5 billion, which is more than 76% of all utility losses. Electric systems sustain the second largest economic loss at 13% of all utility losses. The remaining subsystems pale in comparison as their individual subsystems do not contribute significant losses to the overall value of utility system losses (See Table 77).

6.1.3.6 Induced Damage

Fires ignited from the initial earthquake are most prevalent in areas of significant shaking. HAZUS-MH predicts 56 ignitions that burn 0.48 square miles. This is fewer ignitions and less burned area than the previous earthquakes. The water demand to extinguish the fires following the earthquake is shown in Figure 94. Most census tracts with fires and water demand are in Arkansas and Mississippi, with some of the highest demands occurring in northeastern Arkansas. Fires are estimated to affect 304 people and damage $19 million of inventory value.

Debris generation is focused in northeastern Arkansas, Memphis, Tennessee, and northwestern Mississippi (See Figure 95). It is interesting to note the dark blue census tract in Mississippi that shows 93 thousand tons of debris. Without a thorough investigation of the county's inventory it is difficult to speculate as to the reason for such large debris values there, though there may be a large number of structures in that specific area. HAZUS-MH estimates a total of 7 million tons of debris, with 3.64 tons attributed to brick and wood. The remaining 3.36 tons is due to concrete and steel. With debris removal occurring in 25 ton truckloads approximately 280,000 truckloads are required to remove all the debris generated from the southwest scenario earthquake.

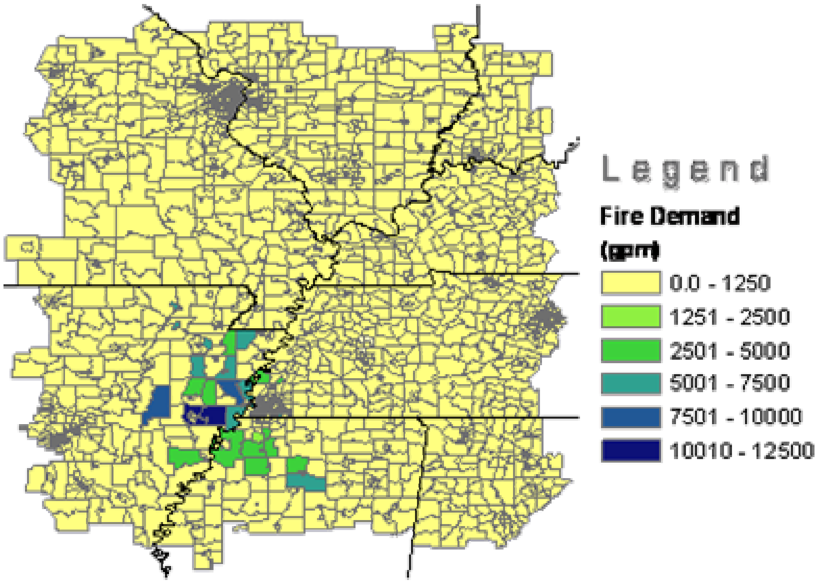


Figure 94: Fire Demand (gpm) – SW Level I

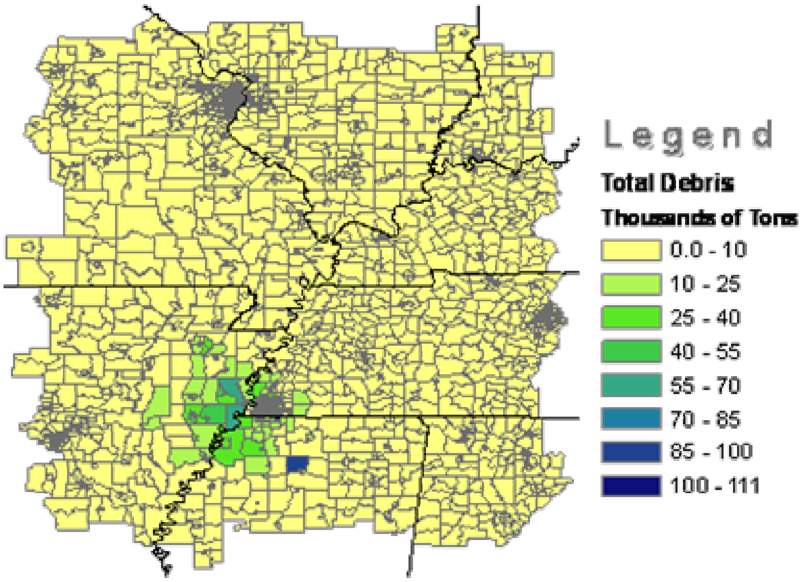


Figure 95: Total Debris (Thousands of Tons) – SW Level I

6.1.3.7 Social and Economic Losses

Displaced households and temporary housing requirements are key values for response and recovery planning as they determine the amount and locations of temporary housing for a given hazard. For the southwest epicenter displaced households and temporary housing needs are quantified in Table 78. Arkansas, Mississippi and Missouri see nearly all the housing demand. The large housing need in Tennessee is due almost entirely to the extensive damage in Memphis. Being so close to the southwest epicenter the city experiences some of the highest levels of damage in the region which is compounded by its urban nature. As a result over 99% of all Tennessee's housing needs are located there.

Table 78: Shelter Requirements – SW Level I

	Displaced Households	Temporary Housing
Alabama	0	0
Arkansas	4,000	1,239
Illinois	0	0
Indiana	0	0
Kentucky	0	0
Mississippi	1,227	305
Missouri	4	1
Tennessee	13,605	4,304
Total	***18,836***	***5,849***

Table 79: Casualties - 2 PM – SW Level I

	Level 1	Level 2	Level 3	Level 4
Commercial	6,570	1,603	221	428
Commuting	6	7	12	2
Educational	1,288	312	45	87
Hotels	36	9	1	2
Industrial	849	200	26	51
Other-Residential	657	144	18	34
Single Family	769	171	24	45
TOTAL	**10,175**	**2,446**	**347**	**649**

The greatest number of casualties occurs at 2 PM, as is the case with the two previous epicenters. Total casualties are reported at 13,616, with the 5 PM estimate second at 11,683. The night time estimate, at 2 AM, is a distant third at 8,659 casualties. The worst case scenario is delineated in Table 79. Approximately 75% of all casualties are minor injuries, with only 7% attributed to major injuries and fatalities. Commercial buildings experience 65% of all minor injuries, with schools second at 13%. Commuting injuries are least, which is expected since not many people are commuting to and from work at this time of day.

Table 80: Direct Economic Losses by State ($ thousands) – SW Level I

	Capital Losses						Income Losses			
	Structural Damage	Non-Structural Damage	Contents Damage	Inventory Loss	Loss Ratio	Relocation Loss	Capital Related Loss	Wages Loss	Rental Income Loss	Total Loss
Alabama	$2,849	$12,262	$5,456	$262	0.06	$43	$692	$988	$791	**$23,343**
Arkansas	$517,693	$1,494,550	$466,048	$18,058	3.27	$12,739	$120,857	$168,595	$165,211	**$2,963,750**
Illinois	$1,645	$5,825	$2,802	$68	0.02	$15	$159	$210	$348	**$11,072**
Indiana	$246	$620	$382	$36	0.00	$1	$17	$20	$33	**$1,356**
Kentucky	$3,070	$11,375	$5,347	$184	0.05	$41	$551	$743	$752	**$22,063**
Mississippi	$303,736	$825,625	$267,295	$16,337	2.26	$7,082	$99,555	$140,979	$99,083	**$1,759,692**
Missouri	$20,898	$55,806	$23,259	$1,004	0.16	$363	$4,139	$5,707	$5,205	**$116,382**
Tennessee	$1,317,392	$3,920,022	$1,319,629	$48,383	0.81	$31,091	$403,972	$539,447	$464,701	**$8,044,636**
TOTAL	***$2,167,528***	***$6,326,085***	***$2,090,218***	***$84,332***		***$51,375***	***$629,942***	***$856,688***	***$736,124***	***$12,942,294***

Table 81: Direct Economic Losses by General Occupancy ($ millions) – SW Level I

		Single Family	Other Residential	Commercial	Industrial	Others	TOTAL
Income Losses	**Wage**	$0.00	$57.70	$732.47	$38.10	$28.42	**$856.69**
	Capital-Related	$0.00	$24.88	$573.56	$23.23	$8.28	**$629.95**
	Rental	$164.31	$230.83	$304.70	$14.86	$12.21	**$726.91**
	Relocation	$18.13	$6.32	$21.48	$1.12	$4.33	**$51.38**
	SUBTOTAL	**$182.44**	**$319.73**	**$1,632.21**	**$77.31**	**$53.24**	**$2,264.93**
Capital Stock Losses	**Structural**	$801.88	$384.99	$730.78	$144.51	$105.37	**$2,167.53**
	Non-Structural	$2,846.04	$1,365.42	$1,565.63	$319.24	$229.76	**$6,326.09**
	Content	$855.73	$269.99	$670.19	$194.04	$100.27	**$2,090.22**
	Inventory	$0.00	$0.00	$30.80	$51.11	$2.43	**$84.34**
	SUBTOTAL	**$4,503.65**	**$2,020.40**	**$2,997.40**	**$708.90**	**$437.83**	**$10,668.18**
	TOTAL	***$4,686.09***	***$2,340.13***	***$4,629.61***	***$786.21***	***$491.07***	***$12,933.11***

Economic losses for buildings are divided by state in Table 80. Tennessee sees the greatest loss in every category with total state losses estimated at over $8 billion which equates to two-thirds of all building losses. Arkansas in second with over $2.9 million or 23% of all building losses. Northern states such as Illinois and Indiana and Kentucky experience minimal losses in comparison to the southern states. Additional building loss characterizations are presented in Table 81. All residential buildings comprise 54% of all building losses, while 35% is attributed to commercial buildings. Industrial and other buildings contribute roughly 10% of all building losses at $1.3 million.

Transportation losses follow similar trends to those shown for building direct losses. Table 82 highlights transportation losses by state. Arkansas shows the greatest transportation lost at $262 million which translates to 45% of regional transportation losses. Tennessee follows with $203 million at 35% of overall transportation losses. As expected, northern states incur much smaller losses due to their great distance from the epicenter. Losses are also broken down by subsystem type, as seen in Table 83.

Highway systems show the greatest loss value at $310 millions which is attributes solely to bridges. This equates to 1.2% of the total value of bridge inventory. Again, ferry facilities are showing complete damage to all facilities which was shown in the analysis of the central epicenter to be incorrect. Railway facilities also show a high loss ratio of 5.7, followed closely by port facilities at 5.0 and airport facilities at 4.1. The transportation system overall, however; gives a loss ratio of 3%.

Table 82: Direct Transportation Losses by State ($ thousands) – SW Level I

	Transportation							
	Highway	**Railway**	**Light Rail**	**Bus Facility**	**Ports**	**Ferries**	**Airports**	**Total**
Alabama	$1,447	$268	$0	$30	$1,285	$0	$1,359	**$4,389**
Arkansas	$167,351	$11,738	$0	$674	$17,057	$0	$65,761	**$262,581**
Illinois	$1,293	$401	$0	$101	$1,696	$2,420	$3,655	**$9,566**
Indiana	$23	$86	$0	$2	$270	$0	$510	**$892**
Kentucky	$1,141	$710	$0	$54	$3,714	$1,068	$2,524	**$9,212**
Mississippi	$25,264	$1,169	$0	$468	$2,650	$0	$23,524	**$53,076**
Missouri	$8,507	$2,041	$0	$618	$5,644	$1,123	$14,170	**$32,103**
Tennessee	$105,157	$30,992	$0	$1,478	$38,208	$959	$26,516	**$203,309**
TOTAL	***$310,182***	***$47,406***	***$0***	***$3,426***	***$70,524***	***$5,570***	***$138,019***	***$575,128***

Table 83: Direct Transportation Losses by Subsystem Component – SW Level I

	Inventory Value	**Economic Loss**	**Loss Ratio**
Highway Bridges	$25,505,730,000	$310,180,000	1.22%
Railway Bridges	$53,160,000	$150,000	0.28%
Railway Facilities	$830,860,000	$47,260,000	5.69%
Bus Facilities	$90,310,000	$3,430,000	3.80%
Ferry Facilities	$5,570,000	$5,570,000	100.00%
Port Facilities	$1,413,120,000	$70,520,000	4.99%
Airport Facilities	$3,366,410,000	$138,020,000	4.10%

Utility systems losses are illustrated by state in Table 84 & Table 85. Arkansas incurs the greatest loss at $1.14 billion, followed by Tennessee with $422 million and another 21% of total utility losses. Additional losses are divided up by subsystem type. Waste water facilities show the greatest losses at $1.45 billion and loss ratios of 1.34 and 1.52 for facilities and distribution lines, respectively. Oil system facilities are another critical loss group with the largest loss ratio, 3.75. Natural gas distribution lines exhibit a loss ratio of 2.44, though pipeline runs are based on numerous assumptions within HAZUS-MH and thus the uncertainty in that value is high.

Table 84: Utility System Losses by State ($ thousands) – SW Level I

	Utility Systems						
	Potable Water	Waste Water	Oil Systems	Natural Gas	Electric Power	Communication	Total
Alabama	$2,672	$6,199	$0	$1,962	$2,094	$10	**$12,937**
Arkansas	$81,209	$898,397	$31	$50,359	$107,640	$603	**$1,138,238**
Illinois	$3,819	$12,356	$0	$2,402	$1,286	$6	**$19,870**
Indiana	$520	$540	$0	$420	$82	$0	**$1,562**
Kentucky	$3,094	$11,400	$0	$1,823	$1,654	$12	**$17,983**
Mississippi	$17,919	$206,700	$0	$14,810	$34,856	$203	**$274,489**
Missouri	$19,257	$100,923	$0	$7,980	$17,711	$69	**$145,941**
Tennessee	$45,160	$303,716	$152	$19,216	$53,287	$559	**$422,090**
TOTAL	***$173,650***	***$1,540,232***	***$184***	***$98,972***	***$218,610***	***$1,463***	**$2,033,110**

Table 85: Direct Utility Losses by Subcomponent – SW Level I

	Inventory Value	Economic Loss	Loss Ratio
Potable Water Facilities	$8,314,300,000	$57,880,000	0.70%
Potable Water Distribution Lines	$10,011,200,000	$115,770,000	1.16%
Waste Water Facilities	$108,128,400,000	$1,448,670,000	1.34%
Waste Water Distribution Lines	$6,006,700,000	$91,560,000	1.52%
Natural Gas Facilities	$117,100,000	$1,090,000	0.93%
Natural Gas Distribution Lines	$4,004,500,000	$97,880,000	2.44%
Oil Facilities	$4,800,000	$180,000	3.75%
Electric Power Facilities	$17,087,400,000	$218,610,000	1.28%
Communication Facilities	$89,600,000	$1,460,000	1.63%

Regional losses are totaled by state and type and appear in Table 86. Tennessee incurs the greatest direct economic loss of any state, by far. Over $8.6 billion in total losses occur there, which translates to 58% of regional losses. Arkansas contributes another $4.36 billion and 28% of total regional direct losses. Illinois, Indiana and Kentucky are again shown to incur minimal losses with overall values less than 3% each. The southwest epicenter generates over $12.9 billion of direct building economic losses over the entire study region. This equates to almost 83% total direct losses. The ratio of losses represented here is much different than the previous epicenter, as buildings account for such a larger percentage and utilities are only 16% of all losses.

Induced losses for the southwest scenario earthquake show significant employment gains in the first year. Employment is more than doubled due to recovery efforts and related jobs. Economic losses from business interruptions, however; generate over $18 billion in losses. It is not until the fourth year after the earthquake that the region stops losing money and does not require the large number of jobs for rebuilding and other recovery efforts. The economic and employment recovery timeline is outlined in Table 87.

Table 86: Total Direct Economic Loss – SW Level I

	Total Loss ($ Thousands)
Alabama	$40,668,286
Arkansas	$4,364,569,521
Illinois	$40,508,005
Indiana	$3,809,314
Kentucky	$49,257,886
Mississippi	$2,087,257,788
Missouri	$294,425,184
Tennessee	$8,670,035,402
TOTAL	**$15,550,531,387**

	Total Loss ($ Billions)
Buildings	$12.9
Transporation	$0.6
Utilities	$2.0
Total	**$15.6**

Table 87: Indirect Economic Losses without Aid – SW Level I

	Loss	Total	%
First Year	Employment Impact	5,639,544	189.37
	Income Impact	18,530	13.07
Second Year	Employment Impact	2,239,230	75.19
	Income Impact	10,492	7.40
Third Year	Employment Impact	53,048	1.78
	Income Impact	2,669	1.88
Fourth Year	Employment Impact	2,989	0.10
	Income Impact	-227	-0.16
Fifth Year	Employment Impact	170	0.01
	Income Impact	-390	-0.27
Years 6 to 15	Employment Impact	9	0.00
	Income Impact	-399	-0.28

6.2 Improved Level I Analysis

Improved Level I analysis still maintains almost all the HAZUS-MH default settings used in the Level I analysis, though now the regional hazard is updated with NEHRP site classes. While NEHRP recognizes site classes ‘A’ thru ‘F’ with site class ‘F’ being soils that require special evaluation, HAZUS-MH only permits that use of classes ‘A’ thru ‘E’, where ‘E’ represents very soft soils. The incorporation of these site class factors adjusts the ground motion to reflect the manner in which these soil types affect the attenuation of ground shaking. This level of analysis was completed for each of the three regional epicenters and comparisons are made between the baseline Level I and the updated hazard data in preliminary work.

As discussed earlier the regional hazard maps developed by USGS account for regional site class variations in the determination of ground motion. A second set of Improved Level I analyses are completed with USGS ground motions and compared to the analyses completed with the ground motions developed by scaling CEUS attenuations by the applicable site class factors. USGS-developed ground motions employing a line source event are more intense for seismic event on all three fault extensions; northeast, central and southwest. More intense ground motions generate more damage and greater losses and thus the USGS ground motions (considering site affects) are employed for all Improved Level I analyses.

6.2.1 Northeast Epicenter

6.2.1.1 Ground Motion

Ground motions are directly affected by the incorporation of site class information. Modified ground shaking maps are illustrated in Figure 96 -Figure 99. Based on the site class maps data obtained during map development the northeast source fault segment is located in a region of intense ground shaking. Maximum peak ground acceleration at the source is increased significantly to 1.38*g*. This is a 57% amplification of maximum peak ground acceleration. No longer is PGA attenuated in concentric

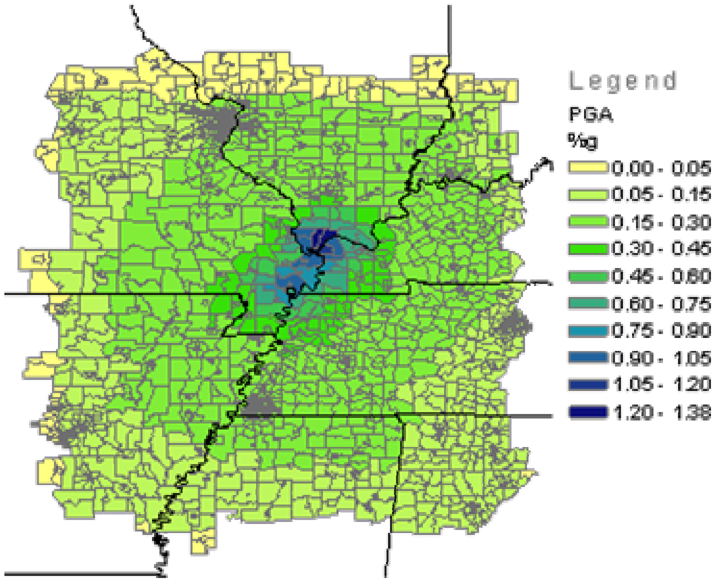


Figure 96: Improved Site Class PGA – NE Improved

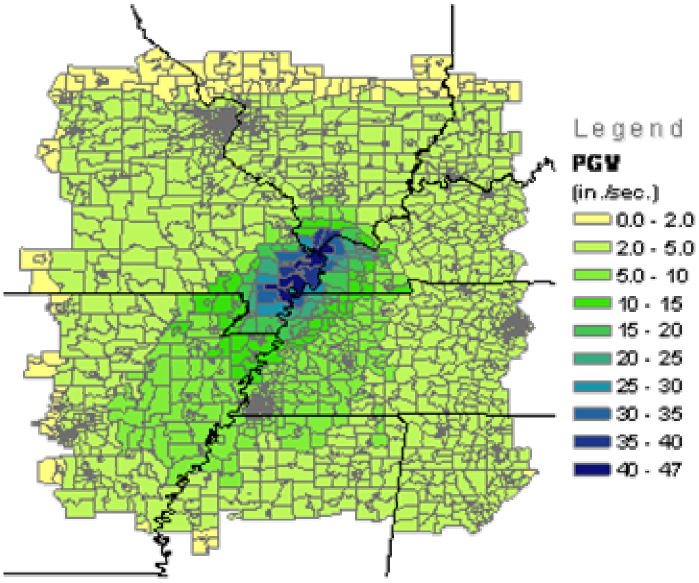


Figure 97: Improved Site Class PGV – NE Improved

circles, radiating from the epicenter, but rather a range of moderate to intense shaking values between 0.3*g* and 1.2*g* surrounding the proposed northeast extension of the New Madrid Fault. Maximum peak ground velocity is amplified to 47 in./sec. at the epicenter, which is a 23% increase over the default maximum PGV. Peak ground velocities decrease rapidly in all directions except the southwest direction, which may indicate some directivity of fault rupture. Overall, however, PGV values are significantly higher for the improved site class scenario. Short-period spectral acceleration is roughly the same nearest the source through greater in the southwest portion of the region than in the previous default case. Default maximum S_a 0.3 sec. of 2.2*g* drops to 2.1*g* when site class data is added. Long-period spectral accelerations increase to a maximum of 1.28*g* from 0.8*g* in the default case. Additionally, long- period accelerations show greater values in the northeast near the fault and in the southwest, along the more southern extensions of the proposed fault. Northern and western portions of the region show much lesser shaking at long periods than 0.15*g*.

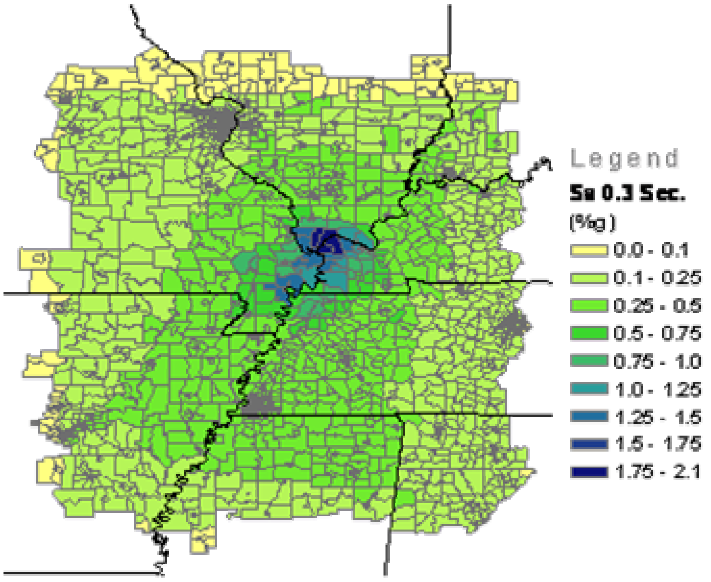


Figure 98: Improved Site Class S_a 0.3 Sec. – NE Improved

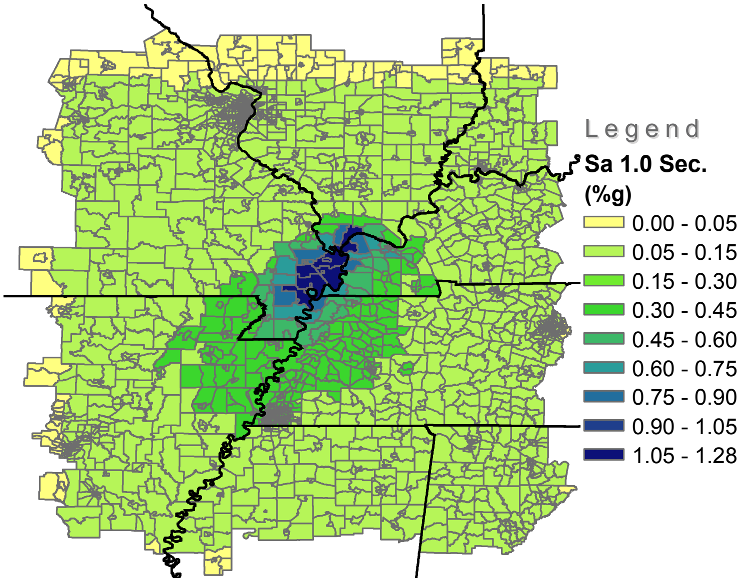


Figure 99: Improved Site Class S_a 1.0 Sec. – NE Improved

Spectral displacements at short-periods are reduced to 4.0-inches from 4.19-inches in the default case. While displacements do not decrease in a radial pattern as in the default case, typical short-period spectral displacements still remain between ¼- and ¾-inches throughout the majority of the region. As with other ground motion parameters, displacements increase in northeast Arkansas and western Tennessee and reach displacement values much greater than the default case in those areas. Long-period spectral displacements increase dramatically with the incorporation of site class data (See Figure 100 & Figure 101). Maximum displacement at the source increase to eight-inches

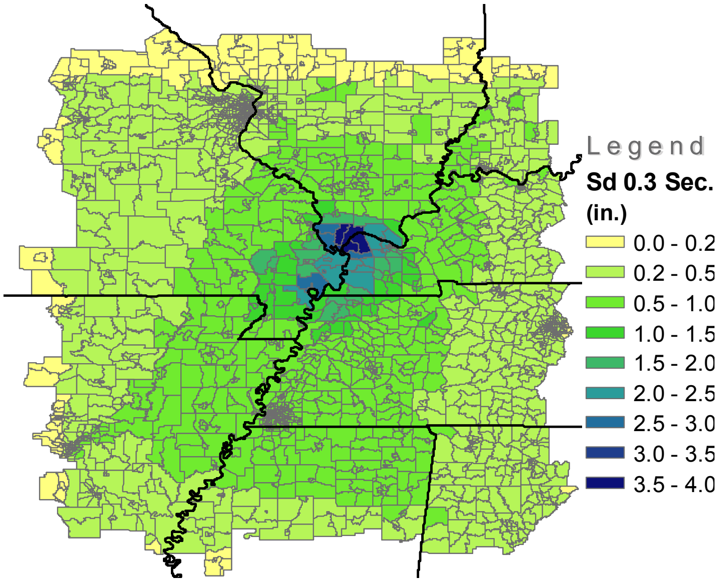


Figure 100: Improved Site Class S_d 0.3 Sec. – NE Improved

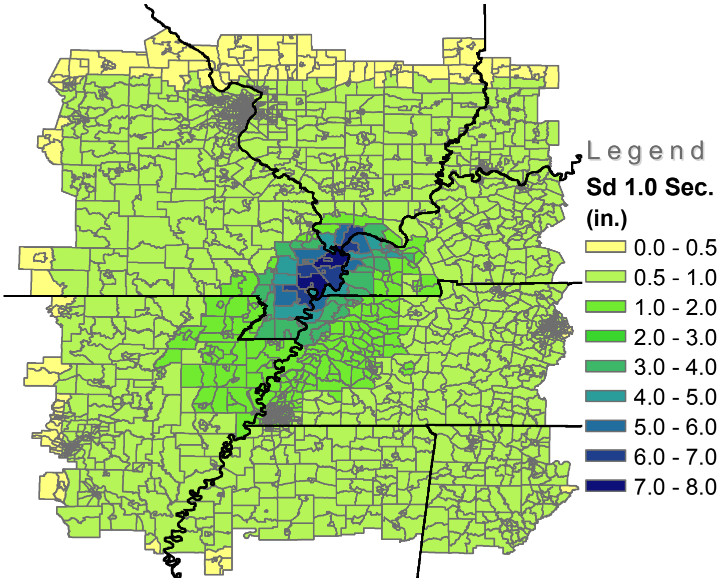


Figure 101: Improved Site Class S_d 1.0 Sec. – NE Improved

from 5.04-inches in the default case. This is an amplification of nearly 60%. Regional displacements also increase and are more randomly dispersed as site classes vary across the region.

6.2.1.2 General Building Stock

Structural damage to the three primary building types increases, not only with regard to damage state probability, but also in terms of area where damage occurs. Light wood frames see the least increase in structural damage of the three primary site class factors the map representing the likelihoods of at least moderate damage are building types. While damage state probabilities increase slightly with the addition of similar to the figure shown for the default case (Figure 102). Unreinforced masonry buildings and mobile homes, however; show substantial differences in at least moderate damage state probabilities. These new damage trends are illustrated in Figure 103 & Figure 104.

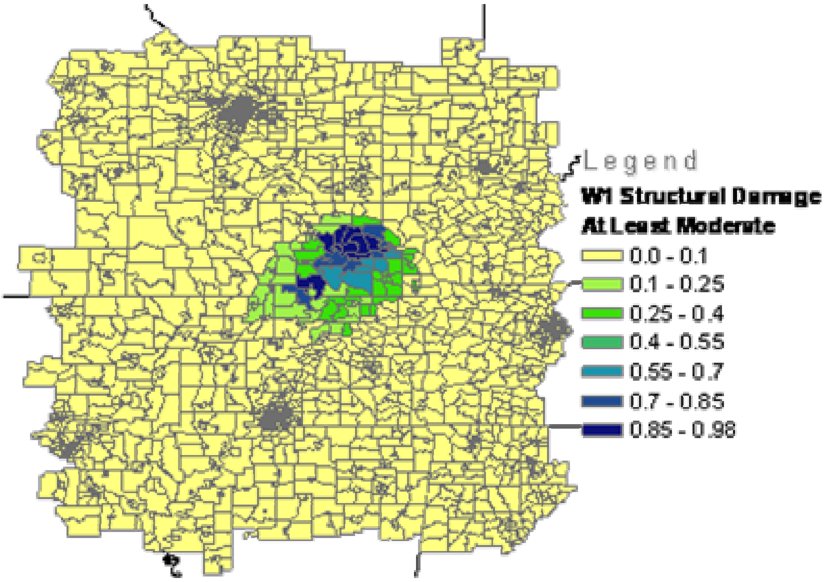


Figure 102: At Least Moderate Structural Damage - W1 - NE Improved

Both building types show the highest probabilities of reaching this damage state nearest the source similar to the default case, though census tracts outside the immediate vicinity of the source experience much higher likelihoods of damage than the default case. Both URMLs and mobile homes show higher damage probabilities extending to the northeast and southwest, with numerous census tracts in the southwestern Kentucky showing higher likelihoods of reaching this damage state. The map of mobile home damage state probabilities is particularly helpful in illustrating this trend. Southern Illinois shows much more damage than the default case for the northeast source. Also, high- and mid-range damage state probabilities extend south into southern Missouri as well as Tennessee and northern Arkansas. This behavior is attributed solely to site class information as such extensive damage is not seen in the default case.

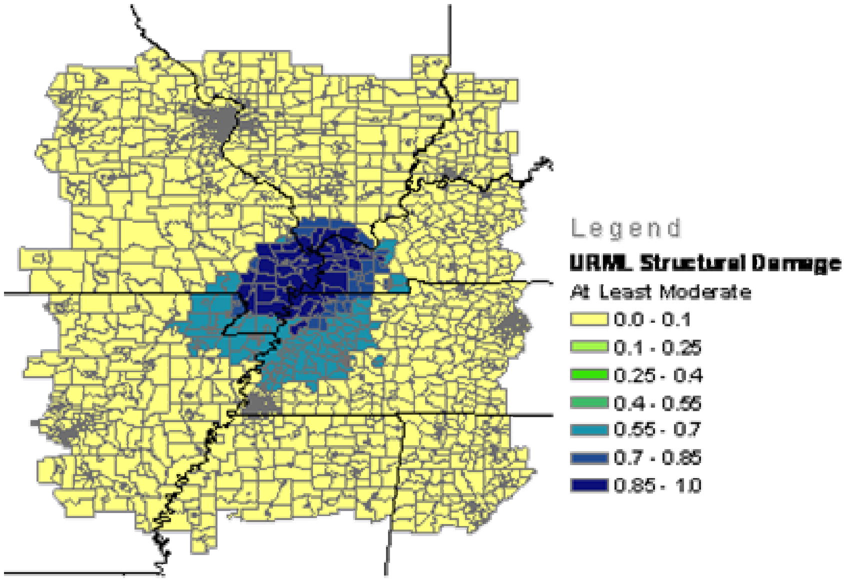


Figure 103: At Least Moderate Structural Damage - URML – NE Improved

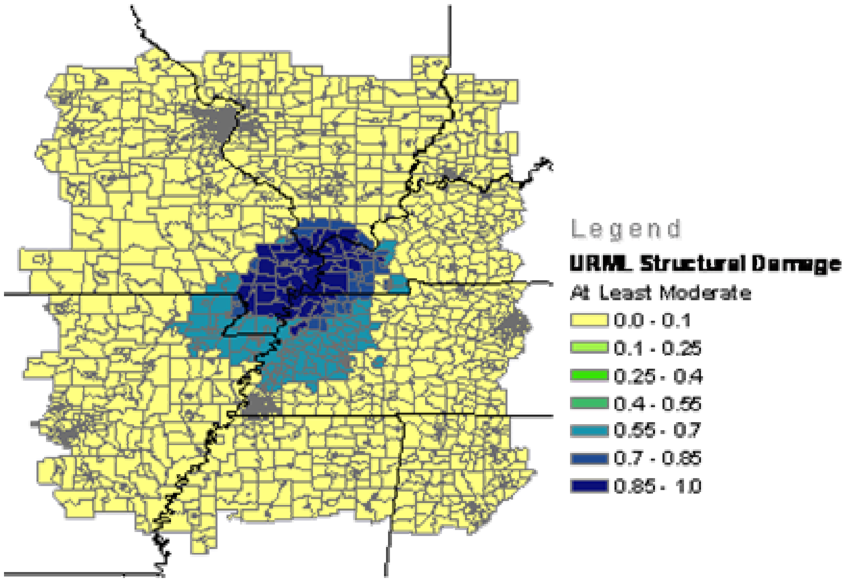


Figure 104: At Least Moderate Structural Damage - MH – NE Improved

Non-structural damage probability distributions for moderate or greater damage are similar to those seen for structural damage. Light wood frames show similar damage trends to those shown in the default case, though minor increases in the area likely to experience damage are evident. Unreinforced masonry buildings and mobile homes exhibit nonstructural acceleration- and drift-sensitive damage probability patterns similar to those shown early for structural damage. Though not illustrated here, the highest probabilities of at least moderate damage are confined to a small area in the immediate vicinity of the fault rupture. Structural damage indicates a larger area where damage is highly likely, though for non-structural damage this area is reduced by roughly half.

Table 88: Building Damage by Building Count and Seismic Code Level – NE Improved

	Light Wood Frame				
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Buildings	395,204	73,905	16,893	2,556	277
Total Low Code Buildings	2,141,386	94,400	26,370	3,465	165
Total Buildings	**2536590**	**168305**	**43263**	**6021**	**442**
				Total Number of Building Type:	2754621
%Total Buildings	***92.085%***	***6.110%***	***1.571%***	***0.219%***	***0.016%***
	Unreinforced Masonry				
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Buildings	28574	13376	9141	3823	4715
Total Low Code Buildings	161035	11115	4645	1465	515
Total Pre-Code Buildings	232980	31164	13326	5412	4216
Total Buildings	**422589**	**55655**	**27112**	**10700**	**9446**
				Total Number of Building Type:	525502
%Total Buildings	***80.416%***	***10.591%***	***5.159%***	***2.036%***	***1.798%***
	Mobile Homes				
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Buildings	12379	10770	13080	5936	3204
Total Low Code Buildings	143048	16799	8577	2110	215
Total Pre-Code Buildings	171036	51593	28206	11409	6218
Total Buildings	**326463**	**79162**	**49863**	**19455**	**9637**
				Total Number of Building Type:	484580
%Total Buildings	***67.370%***	***16.336%***	***10.290%***	***4.015%***	***1.989%***

Damage to regional building types is presented in Table 88. Light wood frame structures are affected by the addition of site class information. Approximately 92% of all light wood frames still exhibit no damage, significantly larger numbers populate the remaining damage categories; slight, moderate, extensive and complete. There are over 60,000 additional cases of slight damage and 300 more collapses. Conversely, moderate damage occurrences decrease by over 50%. Unreinforced masonry buildings show a reduction in buildings experiencing slight damage. This amounts to nearly 13,000 structures. The number of buildings that collapse, however; increases significantly. An additional 4,867 URMs, or 106% more buildings, collapse with the inclusion of site class data. This is the case with mobile homes as well though collapse occurrences increase by 170%. While the overall percentage of mobile homes that show complete damage increases by 1.2%, this equates to an additional 6,100 collapsed structures. Evidently the amplification of ground motion at greater source-to-site distances dramatically impacts unreinforced masonry buildings and mobile homes much more so than light wood frames.

Table 89: Building Damage by State – NE Improved

	Low-Code					
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**	**Total**
Alabama	204,322	1,103	70	0	0	**205,496**
Arkansas	333,701	10,157	855	12	0	**344,724**
Illinois	314,766	13,846	3,658	652	83	**333,005**
Indiana	124,927	3,250	268	4	0	**128,450**
Kentucky	137,448	25,580	22,227	5,317	813	**191,385**
Mississippi	210,404	20,139	1,841	21	0	**232,406**
Missouri	661,321	7,588	547	9	0	**669,465**
Tennessee	466,544	41,086	10,597	1,201	39	**519,466**
Code Total	**2,453,433**	**122,750**	**40,063**	**7,216**	**935**	**2,624,396**
	Moderate-Code					
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**	**Total**
Alabama	0	0	0	0	0	**0**
Arkansas	106,389	27,173	9,986	1,773	59	**145,380**
Illinois	3,902	1,831	2,592	1,467	1,252	**11,045**
Indiana	0	0	0	0	0	**0**
Kentucky	504	2,558	4,171	1,832	964	**10,028**
Mississippi	0	0	0	0	0	**0**
Missouri	51,259	22,105	12,073	5,077	5,568	**96,083**
Tennessee	277,460	45,313	10,872	2,403	450	**336,498**
Code Total	**439,515**	**98,980**	**39,694**	**12,553**	**8,293**	**599,035**
Region Total	**2,892,947**	**221,730**	**79,757**	**19,769**	**9,228**	**3,223,431**
% Region Total	***89.747%***	***6.879%***	***2.474%***	***0.613%***	***0.286%***	

Building damage in northern states is affected by the addition of site class data, as well as southern states show little to no change with regard to building damage distributions for low seismic code level. Illinois, for example, shows nearly 24,000 fewer slightly damaged buildings and almost 33 collapses. Arkansas shows 9,500 more slightly damaged buildings and 800 more cases of moderate damage at the low-code level. The inclusion of site classes dramatically increases the building damage in the small portion of Indiana included in this study region. Kentucky shows major increases at more severe damage levels, most notably though are the additional 800 collapses (See Table 89). Over 25,000 fewer building incur damage in Missouri, while Tennessee exhibits increases in slight and moderate damage at low seismic code levels. State damage changes for low seismic code are similar to those shown by moderate code buildings. At the regional level changes in state damage distributions are almost negligible, with each damage state changing by small margins with the exceptions of Arkansas and Tennessee, which show severe increases in all levels of damage at the moderate-code level.

Table 90: Building Damage by General Occupancy – NE Improved

	None		Slight		Moderate		Extensive		Complete	
	Count	%	Count	%	Count	%	Count	%	Count	%
Agriculture	2,018	0.06%	93	0.03%	49	0.04%	25	0.07%	22	0.11%
Commercial	29,706	0.89%	3,429	1.12%	2,118	1.72%	1,003	2.66%	526	2.61%
Education	252	0.01%	24	0.01%	14	0.01%	6	0.02%	2	0.01%
Government	1,431	0.04%	154	0.05%	86	0.07%	42	0.11%	22	0.11%
Industrial	4,690	0.14%	671	0.22%	475	0.39%	209	0.56%	75	0.37%
Other Residential	446,887	13.45%	88,159	28.73%	53,382	43.39%	20,517	54.50%	10,176	50.50%
Religion	2,245	0.07%	242	0.08%	124	0.10%	53	0.14%	34	0.17%
Single Family	2,835,162	85.33%	214,096	69.77%	66,777	54.28%	15,791	41.95%	9,295	46.12%
TOTAL	**3,322,391**		**306,868**		**123,025**		**37,646**		**20,152**	

General building stock damage by occupancy shows an increase in the number of collapsed buildings, while moderate damage is reduced. Table 90 shows that while single family homes show 18,000 additional instances of moderate damage. ‘Other residential’ buildings with moderate damage decrease by 33,000 structures. Some of these buildings now collapse, while most of the buildings experience no damage. While the number of buildings with no damage increases by 47,000 this is less than 0.5% increase on the regional level.

6.2.1.3 Essential Facilities

Damage to essential facilities is more extensive when site classes are updated. Figure 105 & Figure 106 illustrate revised damage state probabilities for schools and hospitals with at least moderate damage, respectively. Schools exhibit damage probability trends similar to URML buildings discussed for the general building stock. Damage probabilities in excess of 55% extend into the northern tip of Arkansas and southwest Tennessee, with lesser probabilities occurring in Indiana and other northern portions of the study region. The outlying facilities in the north show high likelihoods of at least moderate damage. These schools lie outside the extents of the FEMA hazard maps and are assigned zero ground motions values. As was discussed in the previous section this assignment of ground motion results in random damage to essential facilities. Since this applies to a small number of facilities the increase in regional economic loss is minimal and does not change results significantly. The FEMA maps are used for all improved Level I and Level II analyses which will generate this same behavior in all subsequent regional analyses.

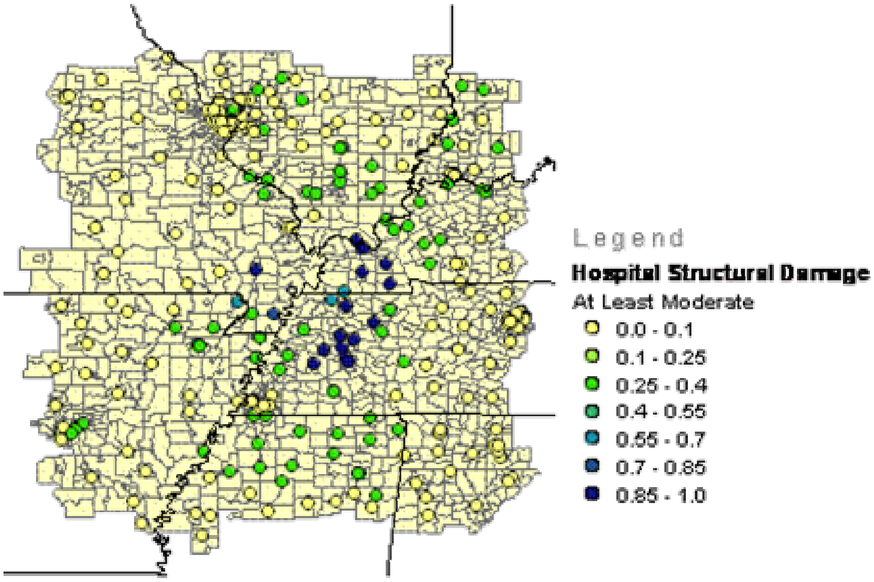


Figure 105: At Least Moderate Damage - Schools – NE Improved

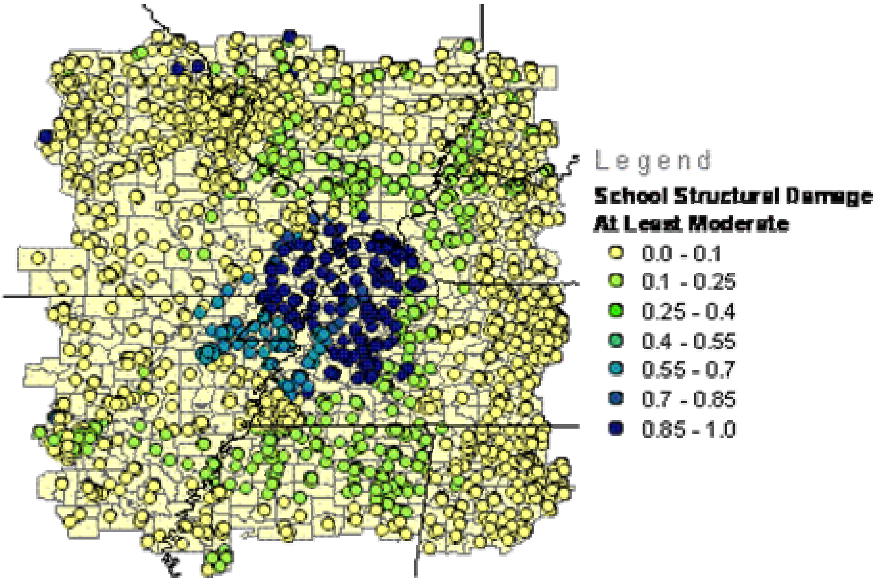


Figure 106: At Least Moderate Damage - Hospitals – NE Improved

Hospitals show similar damage trends. The few hospitals near the source are more than 85% likely to experience at least moderate damage, though these high damage state probabilities extend farther east to Tennessee. Increases in damage are due to two critical factors; site class and building type. The hospitals along Tennessee lie on the banks of the Mississippi River where soils are soft, which amplifies the short-period shaking value which affect these low-rise buildings. In addition, hospitals are categorized as precast concrete buildings with tilt-up walls, PC1. Structural fragilities for building type PC1 indicate moderate damage occurring at a median PGA value of 0.14*g*. Low-rise unreinforced masonry buildings, however; require a 0.17*g* median value to reach moderate damage. The western Tennessee area experiences 0.14*g* to 0.16*g* when soil amplification is included. These PGA values generate moderate damage in PC1 buildings, though shaking values are not intense enough to generate damage in URML structures. This inclusion of site class factors and the small difference in median fragility values for PC1 and URML buildings account for the vast difference in damage state probabilities for these two essential facility types. Since fire and police stations are classified as URML buildings damage trends will be the same as those shown for schools.

Table 91: Essential Facilities Damage – NE Improved

		No. of Facilities		
Classification	Total	At Least Moderate Damage >50%	Complete Damage >50%	With Functionality >50% at Day 1
Hospitals	308	22	3	211
Schools	4,695	460	139	4,170
EOCs	92	19	10	71
Police Stations	1,207	177	50	1,003
Fire Stations	1,465	218	64	1,213

Regional damage totals are shown in Table 91. The increased damage state probabilities shown previously are reflected in the number of fire stations with moderate damage or greater. 96 additional fire stations meet this damage state, which equates to over 6.5% of regional fire stations. The remaining essential facility types experience similar increases in regional building damage with the exception of hospital damage, which decreases. Regional facilities damage is reflected in the functionalities displayed in Table 92. Hospitals are greatly affected by the intensified shaking due to the inclusion of site class factors. Day 1 functionalities drop from 81% of regional hospitals operating to 69%. The recovery timeline functions in HAZUS-MH are not changed thus the recovery of hospitals and all other essential facilities maintain their initial functional percentage differences throughout the 90-day recovery timeline. Police stations and schools also show small reductions in Day 1 functionality, with regional operation dropping to 82.8% and 88.8%, respectively. These estimations show the affect of the modified ground motion on regional recovery and the reduced capacity of regional essential facilities that result.

Table 92: Essential Facilities Functionalities – NE Improved

	Hospitals		**Fire Stations**		**Police Stations**		**Schools**	
	308 Total Strucutres		1465 Total Strucutres		1207 Total Strucutres		4695 Total Strucutres	
	No. Functional	**% of Total Functional**	**No. Functional**	**% of Total Functional**	**No. Functional**	**% of Total Functional**	**No. Functional**	**% of Total Functional**
Day 1	211	68.51%	1213	82.80%	1003	83.10%	4170	88.82%
Day 3	211	68.51%	1215	82.94%	1004	83.18%	4170	88.82%
Day 7	286	92.86%	1247	85.12%	1030	85.34%	4235	90.20%
Day 14	286	92.86%	1247	85.12%	1030	85.34%	4235	90.20%
Day 30	291	94.48%	1383	94.40%	1143	94.70%	4522	96.32%
Day 90	305	99.03%	1401	95.63%	1157	95.86%	4556	97.04%

6.2.1.4 Transportation Systems

Highway bridge damage increases with the incorporation of site affects as well. Greater probabilities of at least moderate damage exist along the length of the Mississippi River where soils are soft and primarily sediment. Over 830 bridges are expected to reach moderate damage or greater, while 283 of those, or 34% of these damaged bridges are predicted to collapse. This amounts to an additional 481 bridges with more than moderate damage over the default case, and almost 242 more collapses. Increased amounts of damage affect bridge functionalities, which are expressed in Table 93. Over 400 fewer bridges are functional the day after the earthquake, and 489 fewer bridges after

Table 93: Highway Bridge Functionalities – NE Improved

Highway Bridge Fuctionality		
Time	No. Functional	% Total Functional
Day 1	29538	97.44%
Day 3	29642	97.78%
Day 7	29662	97.85%
Day 14	29665	97.86%
Day 30	29669	97.87%
Day 90	29921	98.70%

Table 94: Transportation Subsystem Losses – NE Improved

Component	**Loss**	**% Loss**
Highway Bridges	$430,720,000	37.21%
Railway Bridges	$580,000	0.05%
Railway Facilities	$118,530,000	10.24%
Airport Facilities	$337,410,000	29.15%
Bus Facilities	$11,580,000	1.00%
Port Facilities	$253,290,000	21.88%
Ferry Facilities	$5,570,000	0.48%
Total	**$1,157,680,000**	

one month. Despite the lesser number of bridges operational after the earthquake the larger inventory only alters regional functionality percentages by less than 2%.

Highway bridges are greatly affected by the amplification of ground motion due to site affects, similar to the remaining types of transportation; railway, port, ferry, bus and airport facilities. Railway and port facilities experience 34 and 92 additional occurrences of at least moderate damage, respectively. Moreover, 26 more airports show the same level of damage. Transportation losses related to the damage generated by the improved northeast scenario event are shown in Table 94. Bridge losses nearly double from the default case while airport facilities generate $181 million in additional damage. The remaining transportation categories see similar changes in loss.

Table 95: Transportation Facilities Damage – NE Improved

	Region Total	At Least Moderate Damage	Complete Damage
Highway Bridges	30,314	831	283
Railway Bridges	425	8	0
Railway Facilities	393	46	0
Bus Facilities	84	6	0
Ferry Facilities	5	5	5
Port Facilities	691	114	5
Airport Facilities	637	31	0

Damage to transportation facilities is illustrated in Table 95 by facility type. Roughly 3% of all highway bridges experience at least moderate damage while less than 1% experience collapse. Over 16% of all port facilities experience at least moderate damage, while the occurrence of collapse is much less prevalent. In addition there are no cases in which railway bridges, railway facilities, bus facilities and airports collapse.

6.2.1.5 Utility Systems

Damage to utility systems is also vastly altered by the affects of regional site data. Most utility subsystems show significant increases in the number of facilities experiencing moderate damage. This includes 115 additional waste water facilities, 73 communications facilities and 28 potable water facilities. Contrary to the baseline Level I analysis two waste water facilities are expected to collapse. As a result utility system functionalities break down as shown in Table 96. First day functionalities are much less than in the default case. Improving regional site information results in over 250 fewer operational waste water facilities the day after an earthquake. By the seventh day, however; functionalities are close to those for the default case, though still lower.

Table 96: Utility Facility Functionalities – NE Improved

	Utility Facilities Functionality						
	Day 1	Day 3	Day 7	Day 14	Day 30	Day 90	Total
Potable Water	213	236	244	244	245	249	**249**
Waste Water	1295	1532	1592	1592	1608	1644	**1646**
Natural Gas	102	110	111	114	114	114	**114**
Oil Systems	48	49	49	49	49	49	**49**
Electric Power	130	152	157	158	158	158	**158**
Communication	900	931	934	940	940	940	**940**

Table 97: Transportation Facilities Damage - NE Improved

	Region Total	At Least Moderate Damage	Complete Damage
Potable Water	249	36	0
Waste Water	1,646	162	2
Natural Gas	114	12	0
Oil Systems	49	1	0
Electric Power	158	16	0
Communication	940	98	0

Transportation facilities damage is illustrated in Table 97 by type. Waste water facilities show the greatest number of at least moderate damage cases, though this is roughly 10% of the total regional waste water facility inventory. Potable water facilities show the greatest rate of at least moderate damage at roughly 14% of the total inventory. Oil facilities are virtually unaffected by regional ground shaking with only one facility with at least moderate damage. Complete damage only occurs with two waste water facilities which is reflected in the functionality of all facility types.

Service disruptions increase by 45%-75% for pipeline networks. Potable water, waste water and natural gas pipelines are estimated to incur approximately 16,000 to 20,000 additional leaks and 4,000 to 5,000 additional leaks. As shown in Table 98, potable water pipelines experience over 46,000 leaks in the estimated distribution network. The highest leak rate is still seen in natural gas lines, at 0.19 leaks/km, which is almost 73% greater than the 0.11 leaks/km for the default case. Waste water and potable water lines increase by only 0.05 leaks/km, which is over 75% of the initial leak rate. Break rates increase as well, with the greatest break rate occurring with natural gas lines.

Nearly 0.049 breaks/km are expected for natural gas lines. This is a 75% increase in break rate from the 0.028 breaks/km seen in the default case.

Table 98: Pipeline Damage – NE Improved

	Total Pipeline Length (kms)	Number of Leaks	Number of Breaks
Potable Water	500,560	46,111	11,528
Waste Water	300,336	36,470	9,117
Natural Gas	200,224	38,985	9,746
Oil	0	0	0

Table 99: Electric and Potable Water Service Disruptions – NE Improved

		No. of Households without Service				
	Total No. Households	Day 1	Day 3	Day 7	Day 30	Day 90
Potable Water	4,236,197	129,833	102,610	71,793	12,843	0
Electric Power		220,247	144,165	63,994	13,953	271

Further service disruptions for potable water and gas are shown in Table 99. Potable water service is impacted dramatically as nearly 73,000 additional service outages occur at Day 1 when site affects are considered. Default case estimations indicate that potable water service is fully restored after 30 days. This improved hazard analysis, however, shows that nearly 13,000 households are still without potable water a month after the earthquake. Electric service shows 174,000 more outages the day after the earthquake, which is down to an additional 116,000 bridges after three days. Fewer households have power restored after 30 days for the improved hazard case, though there are still 271 households without power after three months. With the default analysis almost all power is restored within this three month recovery period.

Significant increases in utility facility damage generate large increases in utility system losses. While oil system losses increase 35 times with the improved hazard this is still only and additional $140,000. Oil losses, as well as all other utility subsystems are shown in Table 100. Overall utility losses increase over $5.9 billion, which translates to a nearly 170% increase in total utility system losses.

Table 100: Utility Subsystem Losses – NE Improved

Utility System	Loss	% Total
Potable Water Facility	$681,930,000	7.24%
Potable Water Lines	$207,500,000	2.20%
Waste Water Facility	$7,103,990,000	75.45%
Waste Water Lines	$164,110,000	1.74%
Oil Facilities	$180,000	0.00%
Nautral Gas Facilities	$7,050,000	0.07%
Natural Gas Lines	$175,430,000	1.86%
Electric Systems	$1,069,700,000	11.36%
Communication	$6,000,000	0.06%
Total	**$9,415,890,000**	

6.2.1.6 Induced Damage

Fires following the earthquake increases as well with improved site information. Over 120 ignitions are expected in this improved analysis. This is much more than the 50 expected ignitions for the default case. No estimations are provided for affected residents, burned area and economic loss due to fire and thus no comparisons can be made between the improved and default cases for these parameters.

More debris is generated with improved site information. Seven million tons of debris are created in the improved case, as oppose to the five million tons expected with the default case. Approximately 49% of all debris is attributed to concrete and steel with the remainder going to brick and wood. Roughly 280,000 truckloads are required to remove regional debris for the improved case, which is 40% more loads than are required for the default case (See Figure 107).

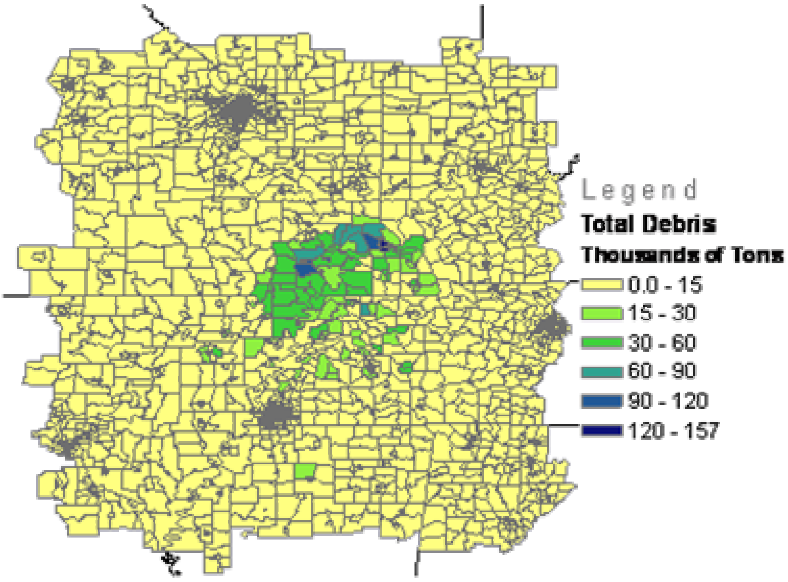


Figure 107: Total Debris (Thousands of Tons) - NE Improved

6.2.1.7 Social and Economic Losses

Updating the site information also increases shelter estimates. Nearly 8,000 additional households are displaced, totaling over 18,500 for the Improved Level I analysis. Table 101 delineates shelter requirements by state. Temporary housing estimates increase by 93% from 2,758 people in need of temporary housing.

Again, casualties are the worst at 2 PM. This analysis shows 12,962 total casualties, which is illustrated in Table 102. Level I estimates only 6,673 casualties, thus the modification of site data contributes and additional 6,300 casualties, or a 94% increase. Most additional casualties are Level I minor injuries, though almost 400 more fatalities are expected with the improvements made.

Table 101: Shelter Requirements – NE Improved

	Displaced Households	Temporary Housing
Alabama	1	0
Arkansas	708	208
Illinois	2,186	645
Indiana	8	2
Kentucky	5,125	1,403
Mississippi	29	8
Missouri	7,637	2,230
Tennessee	2,814	817
Total	***18,508***	***5,313***

Table 102: Casualties - 2 PM – NE Improved

	Level 1	Level 2	Level 3	Level 4
Commercial	5,450	1,421	201	389
Commuting	7	9	16	3
Educational	1,272	343	53	103
Hotels	19	5	1	2
Industrial	759	191	26	50
Other-Residential	720	170	19	35
Single Family	1,225	328	51	95
TOTAL	**9,452**	**2,467**	**367**	**677**

Finally losses by infrastructure components are considered. Building direct losses are illustrated in Table 103. All categories of capital and income losses increase in roughly the same proportion, resulting in an overall direct building loss increase of approximately $5.47 billion. Overall, improving the site data across the region increases building losses by 74%. The most notable state change is in Tennessee, where building losses increase over five times to $3.85 billion from $600 million. Arkansas losses increase to $1.08 billion while Kentucky losses increase to $3.72 billion, or by 232%. Illinois losses, however, are reduced by $910 million, or 39%. Though not pictured here, building-related losses categorized by building type show increases for single family homes and maximum increases for other buildings, though this is $4.2 billion for all residential losses.

Table 103: Direct Building Losses - NE Improved ($ thousands)

	Capital Losses					Income Losses				
	Structural Damage	Non-Structural Damage	Contents Damage	Inventory Loss	Loss Ratio	Relocation Loss	Capital Related Loss	Wages Loss	Rental Income Loss	Total Loss
Alabama	$3,142	$17,072	$8,518	$378	0.08	$39	$498	$741	$753	**$31,141**
Arkansas	$175,263	$514,391	$203,861	$9,862	0.91	$4,102	$49,674	$68,264	$56,144	**$1,081,562**
Illinois	$180,558	$803,609	$355,369	$7,376	3.88	$3,892	$23,748	$31,051	$47,329	**$1,452,933**
Indiana	$15,228	$89,713	$55,712	$3,182	0.33	$263	$2,848	$4,093	$3,744	**$174,784**
Kentucky	$570,279	$1,981,278	$679,309	$21,828	7.47	$12,795	$122,082	$172,151	$158,590	**$3,718,312**
Mississippi	$49,986	$183,317	$87,676	$5,040	0.59	$1,131	$16,322	$24,388	$16,898	**$384,760**
Missouri	$462,978	$1,759,945	$732,174	$27,039	3.98	$9,598	$73,533	$102,840	$123,184	**$3,291,291**
Tennessee	$600,890	$1,797,914	$722,199	$32,388	3.05	$14,081	$204,638	$278,936	$194,099	**$3,845,147**
TOTAL	***$2,058,325***	***$7,147,240***	***$2,844,819***	***$107,093***		***$45,902***	***$493,344***	***$682,465***	***$600,743***	***$13,979,930***

Table 104: Direct Transportation Losses - NE Improved ($ thousands)

	Transportation							
	Highway	Railway	Light Rail	Bus Facility	Ports	Ferries	Airports	Total
Alabama	$2,338	$511	$0	$48	$2,107	$0	$2,514	**$7,518**
Arkansas	$62,046	$5,779	$0	$495	$9,393	$0	$44,389	**$122,102**
Illinois	$104,228	$23,164	$0	$2,473	$47,716	$2,420	$85,238	**$265,238**
Indiana	$440	$8,405	$0	$114	$11,611	$0	$19,985	**$40,555**
Kentucky	$38,417	$29,022	$0	$1,118	$83,920	$1,068	$40,557	**$194,103**
Mississippi	$4,610	$527	$0	$136	$2,248	$0	$13,727	**$21,248**
Missouri	$129,431	$37,150	$0	$5,603	$73,506	$1,123	$84,596	**$331,410**
Tennessee	$89,207	$14,550	$0	$1,596	$22,793	$959	$46,402	**$175,507**
TOTAL	***$430,717***	***$119,108***	***$0***	***$11,584***	***$253,294***	***$5,570***	***$337,409***	***$1,157,681***

Table 105: Transportation Loss Ratios - NE Improved

	Loss Ratio
Highway Bridges	1.69%
Railway Bridges	1.08%
Railway Facilities	14.27%
Bus Facilities	12.83%
Ferry Facilities	100.00%
Port Facilities	17.92%
Airport Fcilities	10.02%

Transportation losses increase by nearly 120% from the default case to $1.16 billion, as shown in Table 104. Bus and airport facilities show large changes in loss values, while railway and port subsystems increase by roughly 190% and 153%, respectively. Highways show the greatest change with $294 million in losses. The additional $251 million translates to 140% of initial highway losses seen in the default case. Illinois and Missouri show the most significant changes, with transportation losses more than twice that of the default case. Kentucky and Tennessee also show sizeable loss increases. Loss ratios for transportation system components are also shown in Table 105.

Changes in utility system losses are comparable to the previous two infrastructure systems. Table 106 delineates utility system losses for the improved site analysis case. A total loss of $9.42 billion is nearly one billion more than the default case. This equates to a 170% increase in utility losses. While Illinois and Missouri utility losses double, losses in Tennessee increase 4.75 times to one billion. Small additions to losses in the remaining states contribute to the overall increase in utility losses. Potable and waste water, natural gas and electric facilities contribute to almost all of the changes in utility losses.

Table 106: Direct Utility Losses - NE Improved ($ thousands)

	Utility Systems						
	Potable Water	**Waste Water**	**Oil Systems**	**Natural Gas**	**Electric Power**	**Communication**	**Total**
Alabama	$2,189	$9,688	$1	$1,250	$5,647	$21	**$18,795**
Arkansas	$33,279	$580,895	$21	$18,369	$83,959	$449	**$716,972**
Illinois	$252,011	$2,107,217	$39	$21,732	$267,240	$1,273	**$2,649,512**
Indiana	$14,424	$63,650	$23	$775	$31,179	$146	**$110,198**
Kentucky	$151,925	$976,789	$4	$26,804	$203,334	$1,265	**$1,360,121**
Mississippi	$8,385	$116,964	$0	$5,199	$13,532	$139	**$144,219**
Missouri	$351,432	$2,571,633	$31	$85,272	$401,149	$1,678	**$3,411,196**
Tennessee	$75,785	$841,269	$59	$23,076	$63,661	$1,032	**$1,004,882**
TOTAL	***$889,431***	***$7,268,104***	***$179***	***$182,477***	***$1,069,702***	***$6,002***	**$9,415,895**

Table 107: Direct Economics Losses by State – NE Improved

	Total Loss		
	Improved	**Diff. from Default**	**% Difference**
Alabama	$0.0575	$0.0444	0.37%
Arkansas	$1.9206	$1.6712	13.84%
Illinois	$4.3677	$0.5985	4.96%
Indiana	$0.3255	$0.0471	0.39%
Kentucky	$5.2725	$3.7554	31.09%
Mississippi	$0.5502	$0.5071	4.20%
Missouri	$7.0339	$1.2843	10.63%
Tennessee	$5.0255	$4.1703	34.53%
Total ($ Billions)	**$24.6**	**$12.1**	

Total direct losses are shown by state in Table 107. Overall, direct economic losses increase by $12 billion, with roughly one-third of that increase occurring in both Kentucky and Tennessee. The modification of site data also generates sizeable loss changes in Arkansas, Illinois and Missouri. Missouri losses increase by over $1.3 billion, while Arkansas shows an additional $1.6 billion in state losses. Furthermore, system loss increases are delineated in Table 108. All systems show increases, though the majority of regional loss increases are attributed to building and utility damage. These two systems comprise nearly 95% or all regional loss increases which equates to $11.4 billion. It is critical to note here, though, that soil amplification generates an additional $12.08 billion in loss for a total regional loss of $24.55 billion for the northeast extension.

Table 108: Direct Economic Losses by Infrastructure System – NE Improved

	Total Loss		
	Improved	**Diff. from Default**	**% Difference**
Buildings	$14.0	$5.5	24.31%
Transporation	$11.6	$11.1	49.29%
Utilities	$9.4	$5.9	26.40%
Total	**$35.0**	**$22.5**	

Finally indirect economic losses increase each year after the earthquake. The first year shows roughly a 50% increase in losses and 2.3 million additional jobs as seen in Table 109. Greater indirect losses persist into the third year after the earthquake. By the fourth year positive economic impacts begin and numerous recovery-related jobs are no longer required.

Table 109: Indirect Economic Loss - NE Improved ($ millions)

	Loss	Total	%
First Year	Employment Impact	7,412,850	248.92
	Income Impact	24,597	17.35
Second Year	Employment Impact	3,430,614	115.20
	Income Impact	16,387	11.56
Third Year	Employment Impact	78,613	2.64
	Income Impact	4,123	2.91
Fourth Year	Employment Impact	4,428	0.15
	Income Impact	-176	-0.12
Fifth Year	Employment Impact	251	0.01
	Income Impact	-419	-0.30
Years 6 to 15	Employment Impact	13	0.00
	Income Impact	-432	-0.30

6.2.2 Central Epicenter

6.2.2.1 Ground Motion

As with the northeast epicenter, modifying the site data to more accurately portray the soil composition of the region alters the ground shaking significantly. Figure 108-Figure 111 shown the new ground motion for the central epicenter. Maximum peak ground acceleration increases to 1.25*g* from 0.67*g* in the default case. Regionally, though, PGA values are greater in the central portion of the region near the source. Generally regional values increase, particularly at mid- and long-range distances. Accelerations greater than 0.1*g* exist in central Arkansas which is not true of the default case. The northern portion of the region feels more intense shaking as well due to the new line source rupture mechanism. Peak ground velocities increase, with the maximum PGV reaching 47 in./sec. This is a 57% increase from the 29.9 in./sec. seen in the default case for the same epicenter. Despite the drastic increase in maximum PGV, most census tracts

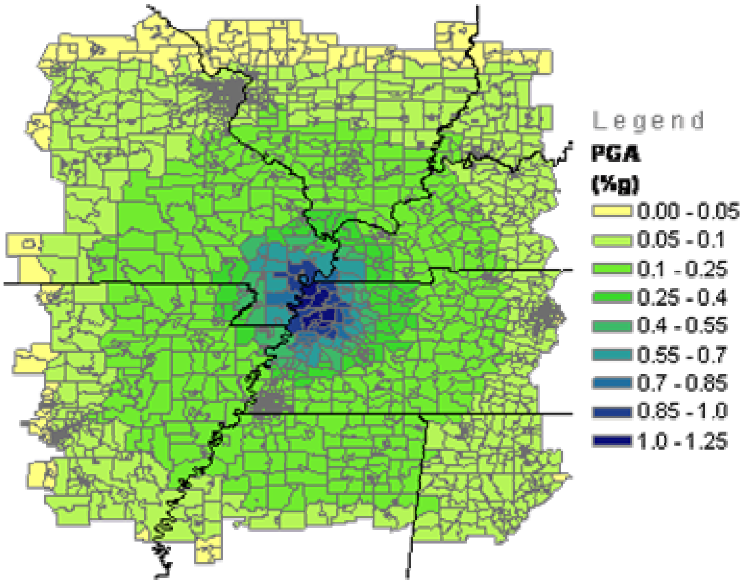


Figure 108: Central Epicenter – Improved PGA

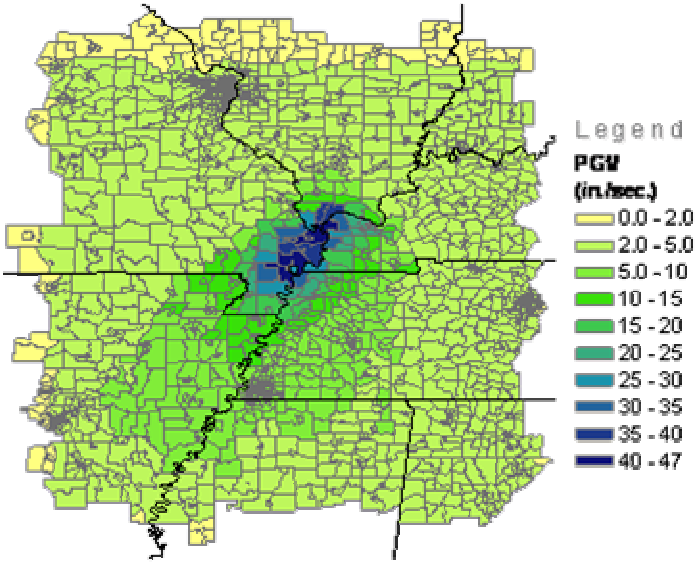


Figure 109: Central Epicenter - Improved PGV

experience 2-15 in./sec., if not less. The southwest shows PGV increase while the eastern and western portions of the region show no change or even a slight PGV reduction. Maximum short-period spectral acceleration is roughly the same for the improved case, with 1.7*g* near the fault and 1.67*g* for the default case. Southern and southwest areas experience more intense short-period spectral accelerations in excess of 0.3*g*, where they previously felt between 0.1*g* and 0.2*g*. Maximum long-period spectral accelerations are also 88% greater for this case with modified site information, reaching 1.5*g*. Northern

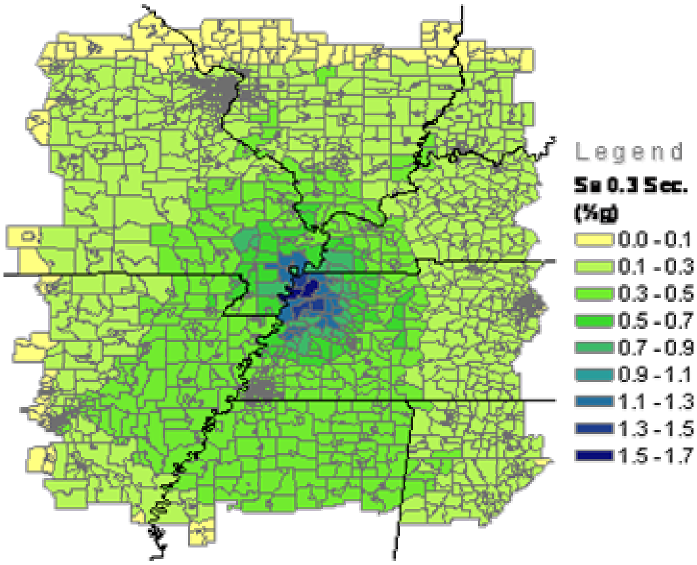


Figure 110: Central Epicenter - Improved S_a 0.3 Sec.

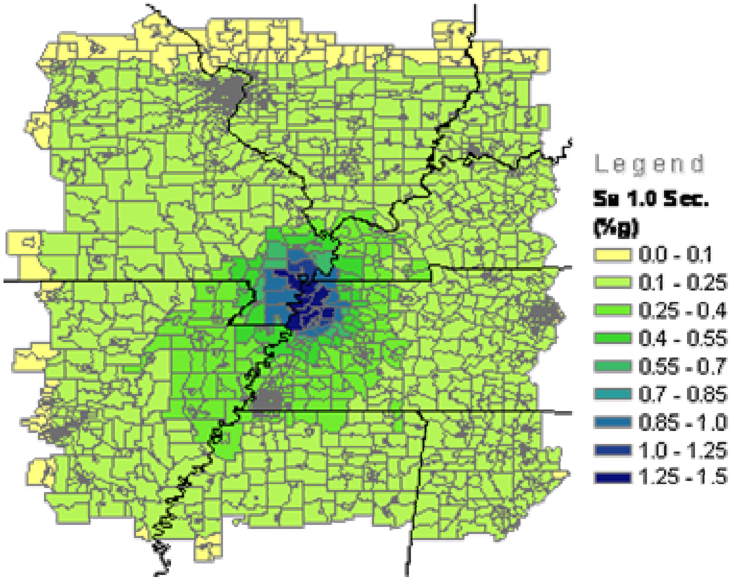


Figure 111: Central Epicenter - Improved S_a 1.0 Sec.

spectral values remain relatively constant with site affects. Increases of 0.05*g* to 0.1*g* are seen in northeast Arkansas and western Tennessee for long-period spectral acceleration. Structural spectral displacements are altered in a manner similar to that seen for short-and long-period spectral accelerations. Figure 112 & Figure 113 show regional displacement trends for both short- and long-period spectral values. The maximum short-period displacement shows a negligible increase of 0.05-inches with improved site information. Outlying portions of Kentucky and Missouri show slightly reduced short-period displacements less than 0.25-inches, while eastern Arkansas, western Tennessee and Alabama show minor increases. Long-period spectral displacements increase region-wide, with the exception of extreme northern areas. Maximum long-period displacements increase to 9.43-inches from 5.04-inches in the default case. This represents an 87% increase in maximum displacement. The Mississippi Embayment region shows typical long-period displacements of 1.5- to 3-inches here, with surrounding areas experiencing lesser long-period displacements of 0.25- to 0.75 inches.

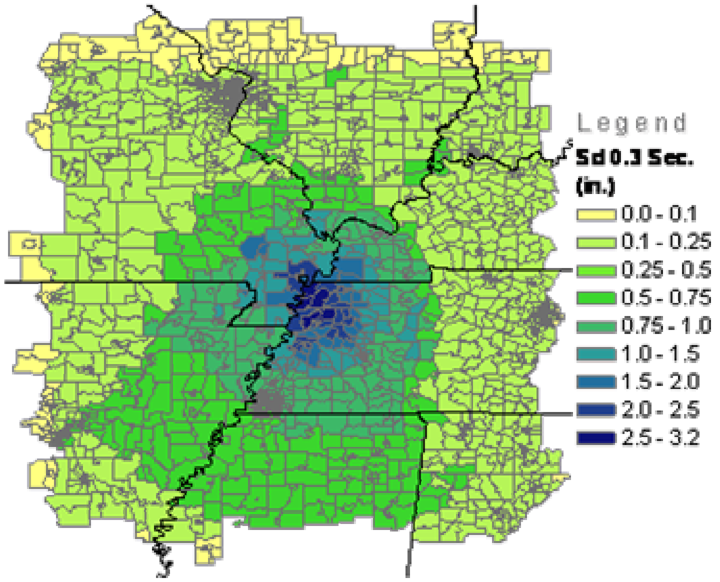


Figure 112: Central Epicenter - Improved S_d 0.3 Sec.

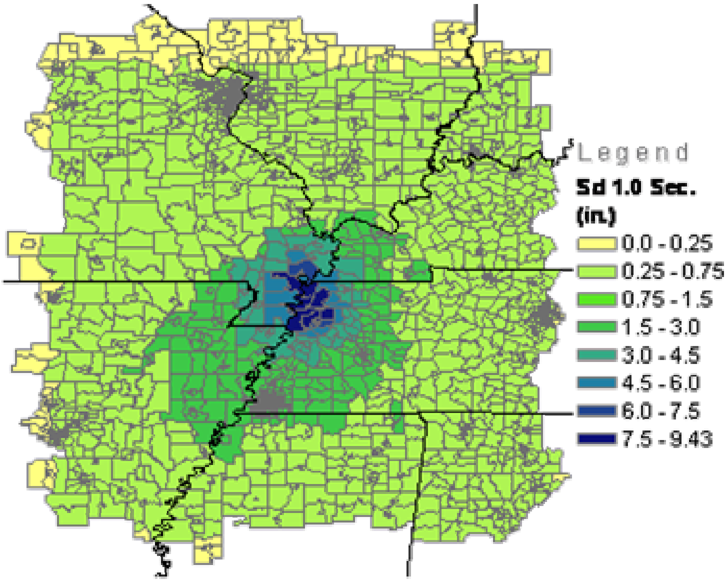


Figure 113: Central Epicenter - Improved S_d 1.0 Sec.

6.2.2.2 General Building Stock

Resulting structural damage is spread over a larger area than the default case. Figure 114 illustrates the extents of at least moderate structural damage to light wood frame construction. In the default case only the census tracts in the immediate vicinity of the epicenter were more than 50% likely to reach this damage state. Modifying the site characteristics, however; expands the region in which moderate or greater damage occurs.

Greater than 50% likelihood of reaching this damage state extends west into Tennessee, with very little damage appearing north of the source fault. Lesser damage likelihoods (<25%) are apparent in southeast Missouri which expands on the damage region shown in the default case. Unreinforced masonry buildings and mobile homes show similar trends for at least moderate damage, with higher likelihoods extending westward into Tennessee. Though not shown here, both types of non-structural damage encompass areas similar to those seen for structural damage.

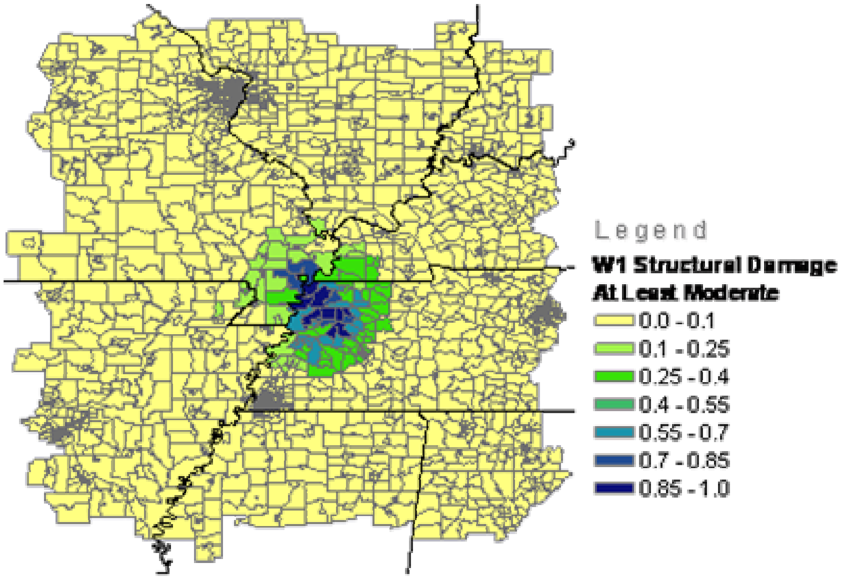


Figure 114: At Least Moderate Structural - W1 - Central Improved

Damage to the three primary building types is delineated in Table 110. Modifying regional site characteristics increases damage to light wood frames, as nearly10% of all buildings are left undamaged, whereas the default case left 5% undamaged. Most damage increases occur with slight and moderate categories where an additional 90,000 and 37,000 buildings, incurring damage, respectively. Moreover, there are over 300 additional collapses of light wood frame buildings with site modifications. Unreinforced masonry buildings experience more damage in this analysis case as nearly 20% of all buildings see some form of damage. Most notably, the number of URM collapses increases nearly five times, to 10,300 from 2,146 structures. Extensive damage cases more than doubles to 11,930 buildings, while slightly damaged building counts decrease by 15%. This indicates that the increases in regional shaking have a significant impact of unreinforced masonry construction. On the contrary, mobile homes experience less damage with over 30% left undamaged in this analysis case, as oppose to 40% undamaged in the default case. Despite the overall decrease in damage, only slight and moderate damage occurrences decrease. The number of extensively and completely damaged structures increases by nearly 8,200 and 8,500 buildings, respectively.

Table 110: Damage by Building Count and Seismic Design Level- Central Improved

	Light Wood Frame				
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Buildings	355,087	104,610	25,718	3,157	277
Total Low Code Buildings	2,138,408	99,464	25,731	2,085	95
Total Buildings	**2493495**	**204074**	**51449**	**5242**	**372**
		Total Number of Building Type:			2754632
%Total Buildings	***90.520%***	***7.408%***	***1.868%***	***0.190%***	***0.014%***
	Unreinforced Masonry				
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Buildings	19369	13597	14852	6169	5668
Total Low Code Buildings	163664	8769	4682	1381	272
Total Pre-Code Buildings	238709	24033	12646	7380	4389
Total Buildings	**421742**	**46399**	**32180**	**14930**	**10329**
		Total Number of Building Type:			525580
%Total Buildings	***80.243%***	***8.828%***	***6.123%***	***2.841%***	***1.965%***
	Mobile Homes				
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Buildings	10704	9658	13897	7051	4045
Total Low Code Buildings	141963	16106	10543	2051	78
Total Pre-Code Buildings	173468	47363	26289	15318	6006
Total Buildings	**326135**	**73127**	**50729**	**24420**	**10129**
		Total Number of Building Type:			484540
%Total Buildings	***67.308%***	***15.092%***	***10.470%***	***5.040%***	***2.090%***

Further damage determinations are carried out on a state level. Table 111 details the number of buildings at various damage levels and classified by state. At low code levels damage to Tennessee buildings increases significantly at the moderate and extensive levels. Kentucky experiences much more extensive and complete damage which is a trend shared by most states. Overall, the frequency of low-code level building collapses and extensive damage cases increase dramatically. At moderate code levels Arkansas collapses increase by 960% to 488 from 46. Also, extensive damage roughly triples in Arkansas. Tennessee shows substantial increases in extensive and complete damage as well. Missouri shows five times as many collapses with modified site data. When both code levels are considered the number of collapses increases to 0.33% of the general building stock, which means an additional 10,500 buildings region-wide. Extensive damage cases also increase by 13,000 across over the entire study region.

Table 111: Building Damage by State - Central Improved

	Low-Code					
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**	**Total**
Alabama	203,275	2,035	184	2	0	**205,496**
Arkansas	329,801	13,704	1,202	17	0	**344,724**
Illinois	326,566	5,461	893	83	2	**333,005**
Indiana	127,541	851	57	1	0	**128,450**
Kentucky	162,361	21,175	6,940	883	26	**191,385**
Mississippi	199,552	28,777	3,823	250	5	**232,406**
Missouri	665,881	3,390	193	2	0	**669,465**
Tennessee	437,043	49,360	28,159	4,448	457	**519,466**
Code Total	**2,452,019**	**124,752**	**41,450**	**5,684**	**490**	**2,624,396**
	Moderate-Code					
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**	**Total**
Alabama	0	0	0	0	0	**0**
Arkansas	96,070	32,243	13,068	3,511	488	**145,380**
Illinois	7,837	2,147	898	157	6	**11,045**
Indiana	0	0	0	0	0	**0**
Kentucky	2,693	3,923	2,522	663	227	**10,028**
Mississippi	0	0	0	0	0	**0**
Missouri	53,330	22,543	9,913	5,076	5,222	**96,083**
Tennessee	227,876	68,199	28,967	7,270	4,187	**336,498**
Code Total	**387,806**	**129,056**	**55,368**	**16,677**	**10,129**	**599,035**
Region Total	**2,839,825**	**253,808**	**96,818**	**22,361**	**10,620**	**3,223,431**
% Region Total	***88.099%***	***7.874%***	***3.004%***	***0.694%***	***0.329%***	

Lastly, the general building stock is classified by general occupancy class and damaged divided on that basis. Single family homes show increases in damage at all levels, particularly with extensive and complete damage. Complete damage cases increase by nearly 400% with 9,800 additional collapses. Commercial damage, however; shows little change at lesser damage levels, though extensive damage and collapse cases increase significantly. All other damage states show more collapses than the default case, while slight and moderate damage levels tend to decrease. Damage trends all occupancy types are illustrated in Table 112.

Table 112: Building Damage by General Occupancy - Central Improved

	None		**Slight**		**Moderate**		**Extensive**		**Complete**	
	Count	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**
Agriculture	2,025	0.06%	83	0.03%	40	0.03%	23	0.05%	35	0.16%
Commercial	29,179	0.89%	3,227	0.99%	2,518	1.83%	1,265	2.74%	593	2.75%
Education	252	0.01%	22	0.01%	15	0.01%	7	0.02%	3	0.01%
Government	1,424	0.04%	147	0.04%	91	0.07%	45	0.10%	29	0.13%
Industrial	4,521	0.14%	637	0.19%	529	0.39%	289	0.63%	144	0.67%
Other Residential	444,046	13.55%	82,923	25.36%	55,338	40.29%	25,900	56.04%	10,915	50.67%
Religion	2,203	0.07%	230	0.07%	153	0.11%	73	0.16%	39	0.18%
Single Family	2,794,284	85.25%	239,759	73.31%	78,677	57.28%	18,615	40.28%	9,784	45.42%
TOTAL	**3,277,934**		**327,028**		**137,361**		**46,217**		**21,542**	

6.2.2.3 Essential Facilities

At least moderate damage state probabilities for hospitals and police stations are displayed in Figure 115 & Figure 116. Hospitals show higher damage probabilities for central census tract due to the peak ground acceleration at which these precast buildings expected to incur damage. Higher damage likelihoods appear south and west of the source primarily, though there are a few hospitals in Missouri with a damage probabilities greater than 85%. Police station damage patterns represent those of school

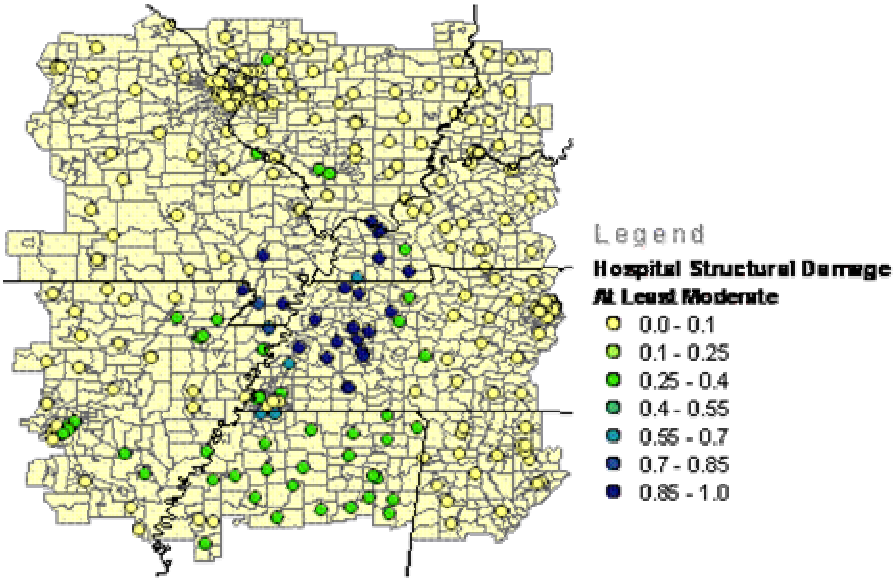


Figure 115: At Least Moderate Damage - Hospitals - Central Improved

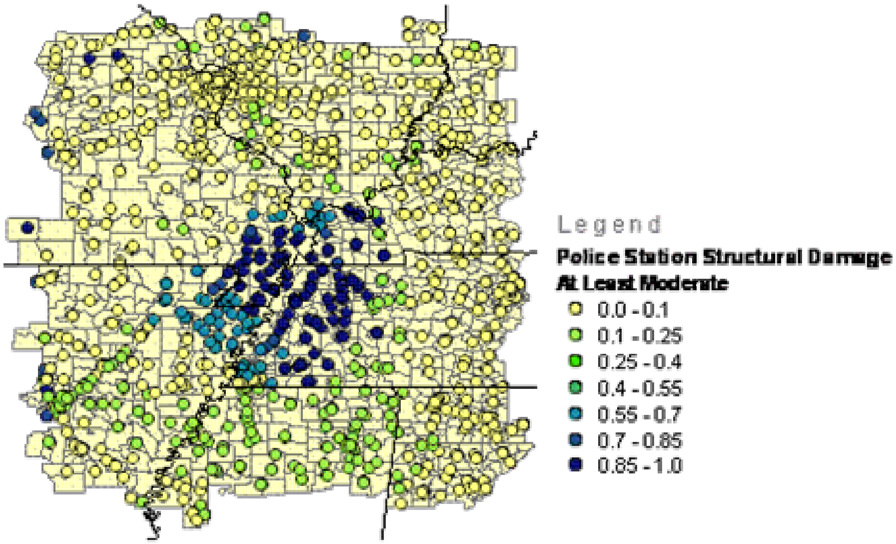


Figure 116: At Least Moderate Damage - Police Stations - Central Improved

and fire stations as all three are unreinforced masonry buildings. Seemingly random damage is illustrated in the extreme north as was discussed previously. The highest probabilities of damage are confined to a region in western Tennessee and northeast Arkansas, and stretching north to Missouri. All essential facilities show more damage when site affects are considered, with the URM facilities seeing the greatest damage increase. An additional 118 police stations, 152 fire stations and 413 schools experience at least moderate damage. Hospitals experience only two more cases of at least moderate damage, though there are only 308 regional hospitals, so this small number has a much greater impact than it would on a facility type with a larger inventory (See Table 113).

Table 113: Essential Facilities Damage - Central Improved

	No. of Facilities		
Classification	**Total**	**Moderate Damage >50%**	**Complete Damage >50%**
Hospitals	308	30	4
Schools	4,695	633	124
EOCs	92	20	4
Police Stations	1,207	221	50
Fire Stations	1,465	253	43

Table 114: Essential Facilities Functionalities - Central Improved

	Hospitals		Fire Stations		Police Stations		Schools	
	308 Total Strucutres		1465 Total Strucutres		1207 Total Strucutres		4695 Total Strucutres	
	No. Functional	**% of Total Functional**	**No. Functional**	**% of Total Functional**	**No. Functional**	**% of Total Functional**	**No. Functional**	**% of Total Functional**
Day 1	222	72.08%	1163	79.39%	962	79.70%	3994	85.07%
Day 3	222	72.08%	1164	79.45%	963	79.78%	3994	85.07%
Day 7	278	90.26%	1212	82.73%	986	81.69%	4062	86.52%
Day 14	278	90.26%	1212	82.73%	986	81.69%	4062	86.52%
Day 30	288	93.51%	1404	95.84%	1136	94.12%	4562	97.17%
Day 90	304	98.70%	1422	97.06%	1156	95.77%	4571	97.36%

Regional percentages of functioning facilities decrease by several percentage points at each post-earthquake interval, as shown in Table 114. Fire and police stations show the significant reduction in the number of operational regional facilities the day after the earthquake approximately 50 each. These facility also recovery more slowly than the default case, with roughly 40 facilities still not operational three months after an earthquake. Over 180 fewer schools are operational the day after an earthquake, though this only drops to about 100 after three months.

6.2.2.4 Transportation Systems

The transportation system also experiences substantially more damage. Highway bridges alone show 563 more cases of at least moderate damage and 287 more collapses. Railway bridges, however; show negligible moderate or complete damage, even when site class modifications are made. Highway bridges are the only transportation component to experience changes in the number of damaged structures. Railways facilities show nine more instances of moderate of more severe damage while port and airport facilities report 29 and 28 additional facilities in the same damage state, respectively (See Table 115).

Table 115: Transportation System Damage - Central Improved

Classification	No. Facilities		
	Region Total	At Least Moderate Damage	Complete Damage
Highway Bridges	30,314	934	294
Railway Bridges	425	2	0
Railway Facilities	393	29	0
Bus Facilities	84	6	0
Ferry Facilities	5	5	5
Port Facilities	691	46	0
Airport Facilities	637	34	0

Table 116: Highway Bridges Functionalities - Central Improved

Highway Bridge Fuctionality

Time	No. Functional	% Total Functional
Day 1	29442	97.12%
Day 3	29520	97.38%
Day 7	29552	97.49%
Day 14	29556	97.50%
Day 30	29559	97.51%
Day 90	29870	98.54%

Table 117: Transportation System Losses - Central Improved

Component	Loss	% Loss
Highway Bridges	$436,120,000	41.47%
Railway Bridges	$290,000	0.03%
Railway Facilities	$97,520,000	9.27%
Airport Facilities	$318,610,000	30.30%
Bus Facilities	$10,060,000	0.96%
Port Facilities	$183,430,000	17.44%
Ferry Facilities	$5,570,000	0.53%
Total	**$1,051,600,000**	

Over 500 fewer bridges are functional the day after the earthquake, with only 29,442 bridges functioning. Table 116 also indicates that 444 bridges are still not operational three months after an earthquake, which is over seven times as many as predicted for the default case. Port and airport facilities show more than 25 fewer facilities operational the day after the earthquake when compared to the default case.

Losses that result from regional damage to the transportation system are delineated in Table 117. Bridges experience a $259 million increase in loss, while railways show only $59 million more for the modified site data case. Port and airport facilities incur an additional $100 million and $172 million in loss, respectively. Ferry and bus losses remain unchanged or increase slightly.

6.2.2.5 Utility Systems

Utility facilities damage trends are illustrated by Figure 117, where at least moderate damage for communication facilities is shown. Clearly, the soft soils and more intense ground motion of the Mississippi Embayment contribute to increased damage state probabilities in that area. Damage is also confined to this small region, whereas other buildings and bridges types show damage extending into extreme northern and southern portions of the study region.

While damage is confined to the central portion of the study region the severity of damage from more intense shaking is evident. Table 118 highlights the numbers of buildings with at least moderate damage as well as collapses. Waste water facilities damage increases dramatically, from 22 to 163 facilities, as does communication facilities damage, 11 to 100 facilities when site affects are introduced. Electric power facilities show 13 more locations of at least moderate damage while oil facilities are relatively are unaffected by the improved analysis. Despite the increases in moderate and extensive damage there are no additional collapses caused by the addition of regional site affects.

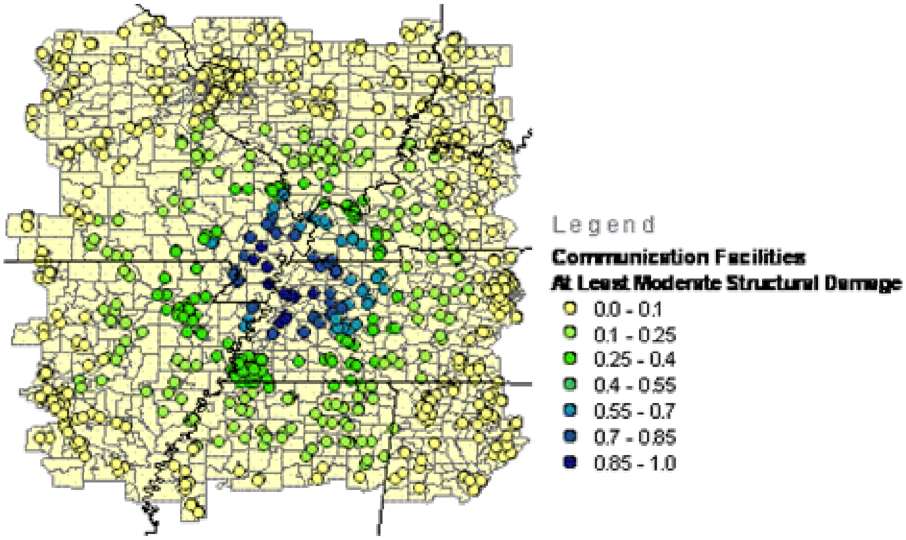


Figure 117: At Least Moderate Damage - Communication Facilities - Central Improved

Table 118: Utility Facility Damage - Central Improved

	# of Facilities				
				With Functionality > 50%	
	Total No.	With at Least Moderate Damage	With Complete Damage	After Day 1	After Day 7
Potable Water	249	23	0	226	243
Waste Water	1,646	163	0	1,319	1,618
Natural Gas	114	7	0	107	112
Oil Systems	49	1	0	48	48
Electric Power	158	15	0	131	157
Communication	940	100	0	915	936

Functionalities of utility facilities are altered from the default case particularly near the source fault. Table 119 displays the functionalities of each utility subsystem at various periods after an earthquake. The day after the earthquake nearly 250 fewer waste water facilities are functioning, when compared to the default case. Also, 18 fewer potable water facilities are operational. Communication, electric power and natural gas systems show similar changes to potable water facilities.

Table 119: Utility Functionalities - Central Improved

	Utility Facilities Functionality						
	Day 1	Day 3	Day 7	Day 14	Day 30	Day 90	Total
Potable Water	226	241	243	243	246	249	**249**
Waste Water	1319	1560	1618	1618	1624	1646	**1646**
Natural Gas	107	111	112	114	114	114	**114**
Oil Systems	48	48	48	49	49	49	**49**
Electric Power	131	155	157	158	158	158	**158**
Communication	915	931	936	940	940	940	**940**

Table 120: Pipeline Damage - Central Improved

	Pipeline Length	Number of Leaks	Number of Breaks
Potable Water	500,560	46,133	11,533
Waste Water	300,336	36,487	9,122
Natural Gas	200,224	39,004	9,751
Oil	0	0	0

Service disruptions increase by 17,000 to 22,000 leaks for various networks, and at least 4,300 pipeline breaks. Table 120 shows the breakdown of pipeline damage. The greatest leak rate is still exhibited by natural gas pipelines, though now there are 0.19 leaks/km instead of 0.10 leaks/km as with the default case. Potable and waste water leak rates of 0.09 leaks/km and 0.12 leaks/km are also greater than the default case, though by lesser margins. Moreover, natural gas break rate nearly doubles to 0.049 breaks/km as a worst case of all break rates.

Further service interruptions by number of households are shown in Table 121. Day 1 service losses triple for potable water service while electric power losses increase by 650%. At three days after an earthquake there are more than four times the default estimate of potable water outages, and eight times as many electricity outages still. Even three months after an earthquake there are still 287 households without power, which is far more than are estimated in the default case.

Table 121: Electric and Potable Water Service Disruptions - Central Improved

		No. of Households without Service				
	Total No. Households	Day 1	Day 3	Day 7	Day 30	Day 90
Potable Water	4,236,197	129,834	102,610	71,793	12,842	0
Electric Power		227,389	143,704	61,274	13,364	287

Finally, utility losses are shown by subsystem in Table 122. Waste water system damage is the most prominent with $5.8 billion, or 77% of all utility losses. Electric systems show the second greatest loss at $834 million. Most utility subsystems exhibit 100% - 300% loss increases over the default case, except for oils systems which experience a 400% increase. Since the overall loss percentage for oil systems is negligible even this large percentage gain is hardly noticed in comparison to total utility systems losses. Overall, utility systems experience a 200% increase in regional loss.

Table 122: Utility Systems Losses - Central Improved

Utility System	Loss	% Total
Potable Water Facility	$485,470,000	6.41%
Potable Water Lines	$207,600,000	2.74%
Waste Water Facility	$5,692,780,000	75.19%
Waste Water Lines	$164,190,000	2.17%
Oil Facilities	$200,000	0.00%
Nautral Gas Facilities	$5,420,000	0.07%
Natural Gas Lines	$175,520,000	2.32%
Electric Systems	$834,400,000	11.02%
Communication	$5,250,000	0.07%
Total	**$7,570,830,000**	

6.2.2.6 Induced Damage

Estimates of fire ignitions following the earthquake 136 ignitions occurring with improved site data. Again, burned area, exposed population and economic impact are not determined. Based on the far greater number of ignitions, however; it can be inferred that these values will be much greater that the default case as well.

Debris generation increases by 200% in this case. Only three million tons of debris are created in the default case, but site improvements add six million tons of debris from more intense shaking in certain areas. This additional debris requires 240,000 more truckloads for debris removal, totaling 360,000 truckloads for the improved case.

6.2.2.7 Social and Economic Losses

Shelter requirements are greatly impacted, along the order of four to five times the estimates shown in the default case. While Alabama still experiences no temporary housing needs, every other state's needs increase dramatically. Missouri alone has nearly 5,000 more displaced households and 1,400 temporary housing needs Tennessee contributes half of all regional shelter needs in both categories, showing 400% more need than in the default case. Table 123 highlights this as well as the increased shelter needs in each state. Also worth noting, Arkansas' shelter requirements increase four-fold in both categories.

Table 123: Shelter Requirements - Central Improved

	Displaced Households	Temporary Housing
Alabama	2	0
Arkansas	1,585	466
Illinois	167	49
Indiana	1	0
Kentucky	1,554	451
Mississippi	90	26
Missouri	7,490	2,220
Tennessee	10,493	3,030
Total	***21,382***	***6,242***

Casualties resulting from the scenario earthquake triple as well. The worst-case is still 2 PM, though now 15,467 casualties are predicted instead of the 4,184 from the default case. Injury level breakdowns are shown in Table 124 for the 2 PM interval.

Minor injuries comprise an additional 10,000 casualties, or a 26% jump. Fatalities also increase more than 450% from 143 in the default scenario to 798 here.

Table 124: Casualties - 2 PM - Central Improved

	Level 1	Level 2	Level 3	Level 4
Commercial	6,413	1,643	230	445
Commuting	9	12	21	4
Educational	1,675	453	70	135
Hotels	20	5	1	2
Industrial	981	250	34	66
Other-Residential	869	206	24	44
Single Family	1,344	355	54	102
TOTAL	**11,311**	**2,924**	**434**	**798**

Direct economic losses for buildings are delineated in Table 125. Overall buildings losses go up for nearly $9.5 billion dollars, from $5.8 to $15.3 billion. This is a 180% increase in building-related losses. Other notable changes include Arkansas building losses which more than double to $1.16 billion, or 11% of all building losses. Tennessee losses increase significantly to $8.38 billion, which is over half of all regional building losses. Though losses in Mississippi are small compared to other states, introducing regional site affects increases building losses more than four times. Kentucky incurs nearly an additional $1 billion, contributing 9% of all building losses.

Table 125: Direct Building Losses ($ thousands) - Central Improved

	Capital Losses					Income Losses				
	Structural Damage	Non-Structural Damage	Contents Damage	Inventory Loss	Loss Ratio	Relocation Loss	Capital Related Loss	Wages Loss	Rental Income Loss	Total Loss
Alabama	$4,595	$24,972	$12,641	$540	0.14	$67	$709	$1,123	$1,096	**$45,742**
Arkansas	$262,609	$791,230	$302,328	$14,141	1.45	$6,028	$65,863	$89,391	$83,271	**$1,614,861**
Illinois	$43,406	$166,825	$78,329	$1,719	0.61	$834	$7,412	$8,925	$11,420	**$318,868**
Indiana	$5,202	$24,621	$15,251	$962	0.11	$55	$582	$738	$969	**$48,380**
Kentucky	$234,821	$665,654	$242,646	$8,190	3.19	$5,469	$65,588	$93,684	$70,876	**$1,386,928**
Mississippi	$113,003	$372,358	$172,878	$11,490	1.38	$2,463	$41,412	$57,485	$34,539	**$805,627**
Missouri	$424,047	$1,427,955	$544,218	$23,110	3.62	$8,640	$65,557	$94,165	$109,766	**$2,697,459**
Tennessee	$1,259,471	$4,211,047	$1,614,977	$66,830	7.25	$30,495	$334,915	$464,659	$402,205	**$8,384,598**
TOTAL	***$2,347,153***	***$7,684,660***	***$2,983,269***	***$126,983***		***$54,051***	***$582,037***	***$810,168***	***$714,142***	***$15,302,463***

Table 126: Direct Transportation Losses ($ thousands) - Central Improved

	Transportation							
	Highway	Railway	Light Rail	Bus Facility	Ports	Ferries	Airports	Total
Alabama	$2,361	$736	$0	$64	$2,820	$0	$3,365	**$9,347**
Arkansas	$79,359	$11,586	$0	$534	$18,120	$0	$58,114	**$167,714**
Illinois	$16,300	$8,157	$0	$1,178	$18,419	$2,420	$38,565	**$85,040**
Indiana	$426	$2,899	$0	$37	$5,451	$0	$9,826	**$18,637**
Kentucky	$13,818	$14,769	$0	$563	$40,341	$1,068	$26,032	**$96,591**
Mississippi	$10,028	$1,255	$0	$310	$3,786	$0	$23,376	**$38,754**
Missouri	$129,188	$30,152	$0	$4,487	$57,348	$1,123	$85,625	**$307,923**
Tennessee	$184,635	$28,257	$0	$2,887	$37,189	$959	$73,707	**$327,634**
TOTAL	***$436,115***	***$97,810***	***$0***	***$10,061***	***$183,475***	***$5,570***	***$318,610***	***$1,051,641***

Table 127: Transportation System Loss Ratios - Central Improved

	Loss Ratio
Highway Bridges	1.71%
Railway Bridges	0.55%
Railway Facilities	11.74%
Bus Facilities	11.14%
Ferry Facilities	100.00%
Port Facilities	12.98%
Airport Fcilities	9.46%

Transportation direct losses experience a 130% gain overall, which equates to an additional $595 million in loss. Table 126 illustrates transportation losses by component. Most notable is the tripling of Tennessee’s total transportation loss to nearly $328 million. Other states contributing substantially to the regional increase are Missouri and Arkansas at $148 million and $103 million, respectively. In addition, transportation loss ratios are shown in Table 127.

Utility losses show approximately a 200% gain over the default case. Table 128 illustrates utility losses by state for the improved site analysis. Missouri incurs roughly one-third of all utility losses while also experiencing a $1.68 billion increase over the default case. Another $640 million gain in economic loss is felt by Arkansas, while Kentucky and Tennessee show substantial increases as well.

Table 128: Direct Utility Losses ($ thousands) - Central Improved

	Utility Systems						
	Potable Water	Waste Water	Oil Systems	Natural Gas	Electric Power	Communication	Total
Alabama	$2,700	$24,119	$1	$1,281	$9,417	$38	**$37,555**
Arkansas	$45,290	$782,872	$21	$18,551	$121,533	$635	**$968,903**
Illinois	$84,778	$625,306	$8	$19,583	$80,040	$344	**$810,060**
Indiana	$5,164	$25,289	$9	$746	$8,083	$34	**$39,323**
Kentucky	$77,361	$487,688	$1	$26,100	$95,828	$519	**$687,496**
Mississippi	$9,494	$222,767	$0	$5,391	$34,888	$274	**$272,814**
Missouri	$331,838	$2,010,853	$6	$85,087	$355,331	$1,264	**$2,784,380**
Tennessee	$136,440	$1,678,078	$151	$24,200	$129,285	$2,145	**$1,970,298**
TOTAL	***$693,065***	***$5,856,972***	***$196***	***$180,939***	***$834,405***	***$5,252***	**$7,570,829**

Total regional losses are expressed in Table 129. Over $15 billion of losses are added to this study region with the incorporation of regional site affects. With the exceptions of Alabama and Indiana, all states show dramatic increases in economic loss. As with previous loss categories, Arkansas, Missouri and Tennessee incur the greatest increases in loss, with Tennessee contributing half of all additional losses due to building losses primarily. Building losses account for the majority of the loss increase to the region with over $9.5 billion falling in that category. Utility losses contribute an additional $5 billion, leaving transportation systems less than 4% of regional losses.

Table 129: Total Direct Economic Losses - Central Improved

Total Loss

	Improved	Diff. from Default	% Difference
Alabama	$0.09	$0.05	0.34%
Arkansas	$2.75	$1.81	11.89%
Illinois	$1.21	$0.63	4.16%
Indiana	$0.11	$0.05	0.34%
Kentucky	$2.17	$1.40	9.19%
Mississippi	$1.12	$0.87	5.74%
Missouri	$5.79	$2.93	19.27%
Tennessee	$10.68	$7.46	49.06%
Total	**$23.9**	**$15.2**	

Total Loss

	Improved	Diff. from Default	% Difference
Buildings	$15.30	$9.52	62.64%
Transporation	$1.05	$0.59	3.92%
Utilities	$7.57	$5.08	33.45%
Total	**$23.9**	**$15.2**	

Finally, indirect economic losses increase, especially in the first year after the scenario earthquake. Over $14.6 million additional jobs are required and $14.8 billion more lost in this first year alone. Table 130 highlights the income and employment breakdown in the first 15 years following the scenario earthquake. Each year indirect losses are 120% in the first year to 180% greater introducing site affects. As with the default case though, the region begins to see positive returns by the fourth year.

Table 130: Indirect Economic Losses ($ millions) - Central Improved

	Loss	Total	%
First Year	Employment Impact	8,134,923	273.17
	Income Impact	26,300	18.55
Second Year	Employment Impact	3,461,549	116.24
	Income Impact	16,363	11.54
Third Year	Employment Impact	78,100	2.62
	Income Impact	4,049	2.86
Fourth Year	Employment Impact	4,400	0.15
	Income Impact	-217	-0.15
Fifth Year	Employment Impact	250	0.01
	Income Impact	-458	-0.32
Years 6 to 15	Employment Impact	12	0.00
	Income Impact	-471	-0.33

6.2.3 Southwest Epicenter

6.2.3.1 Ground Motion

Modified ground motion maps for the southwest extension are shown in Figure 118 - Figure 121**Error! Reference source not found.**. Maximum peak ground acceleration nearest the source is amplified to 0.18*g*- 1.23*g*. Peak ground accelerations decrease rapidly as the source-to-site distance increases. Ground motions drop off quickly to the east and west of the fault, while a greater distance is required to reach negligible accelerations in the northeast and

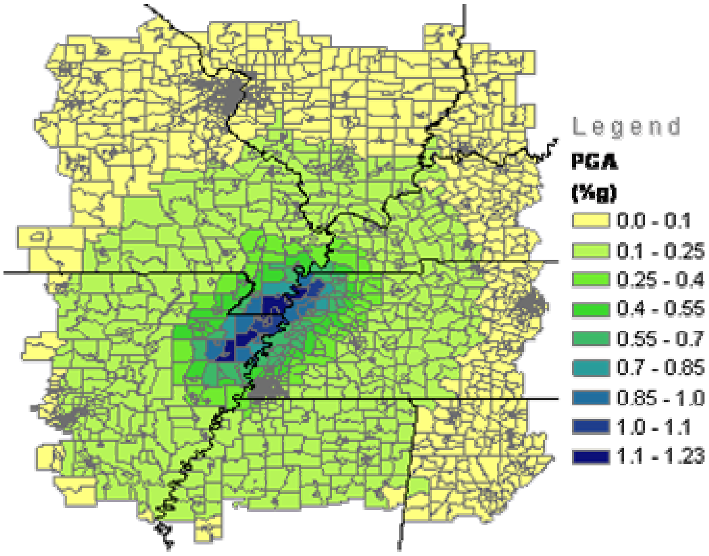


Figure 118: Southwest Epicenter - Improved PGA

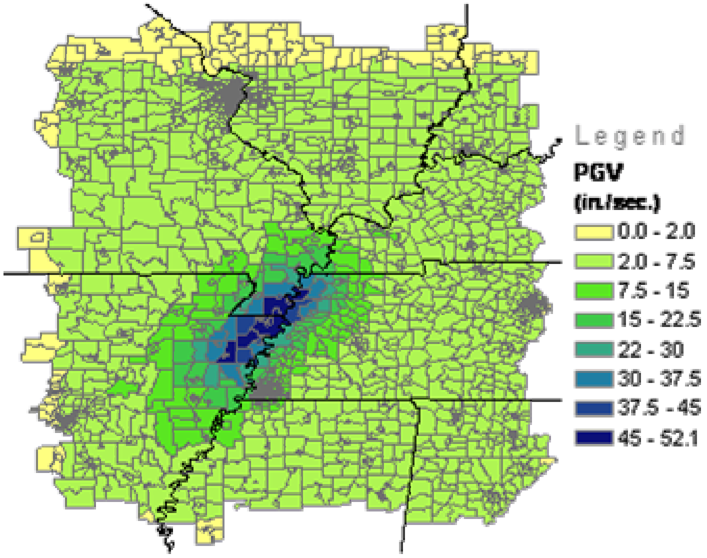


Figure 119: Southwest Epicenter - Improved PGV

southwest directions. Peak ground velocity reaches a maximum of 52 in./sec., which is 8 in./sec. greater than the default case. This is an 18% increase in maximum PGV. The majority of the default region experiences peak ground velocities less than 15 in./sec. while common PGV values for the improved site class region are between 2 in./sec. and 7.5 in./sec. Both short- and long-period spectral accelerations display attenuation trends similar to peak ground velocity. Default case short-period spectral accelerations reach a maximum of 2.62*g*, while the improved site data case only reaches 1.51*g*. This is a 42%

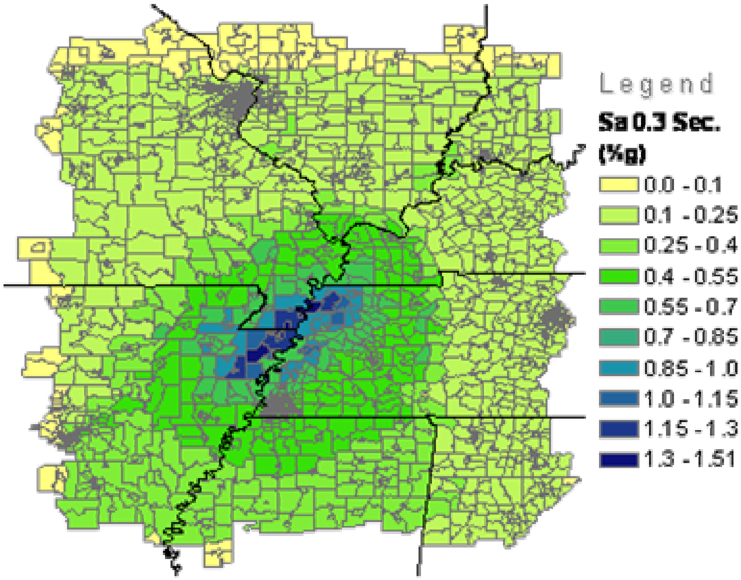


Figure 120: Southwest Epicenter - Improved S_a 0.3 Sec.

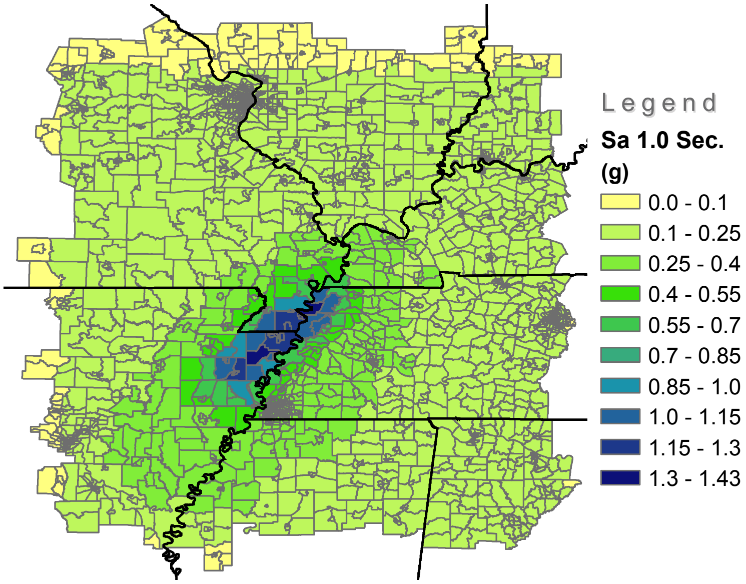


Figure 121: Southwest Epicenter - Improved S_a 1.0 Sec

decrease in maximum S_a 0.3 at seconds. This type of reduction is not common of the two previous fault extensions where short-period acceleration correlated closely between CEUS attenuation maximum and finite fault rupture maximum values. Despite this initial difference the majority of the region shows similar short-period acceleration values to the default case. Long-period spectral accelerations increase region-wide, with a maximum of 1.43*g* which is greater than the 1.2*g* in the default case. Most of the region does not experience such high ground shaking, however; with long-period spectral values less than 0.4*g*.

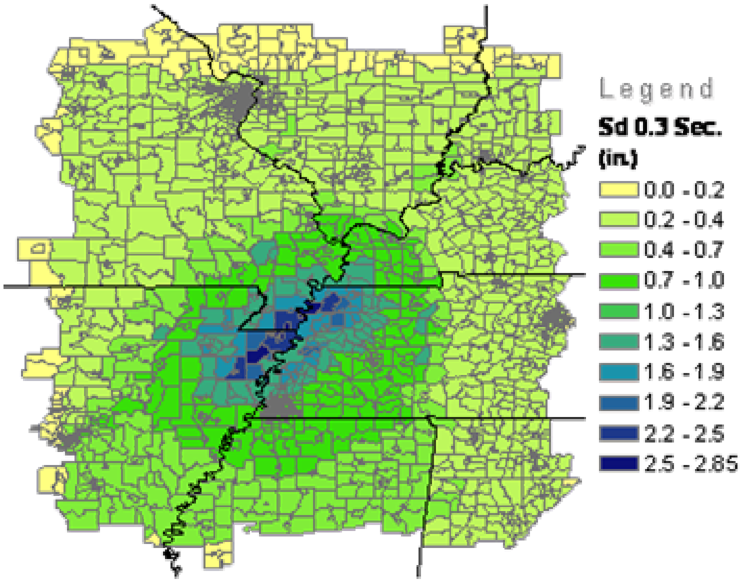


Figure 122: Southwest Epicenter - Improved S_d 0.3 Sec.

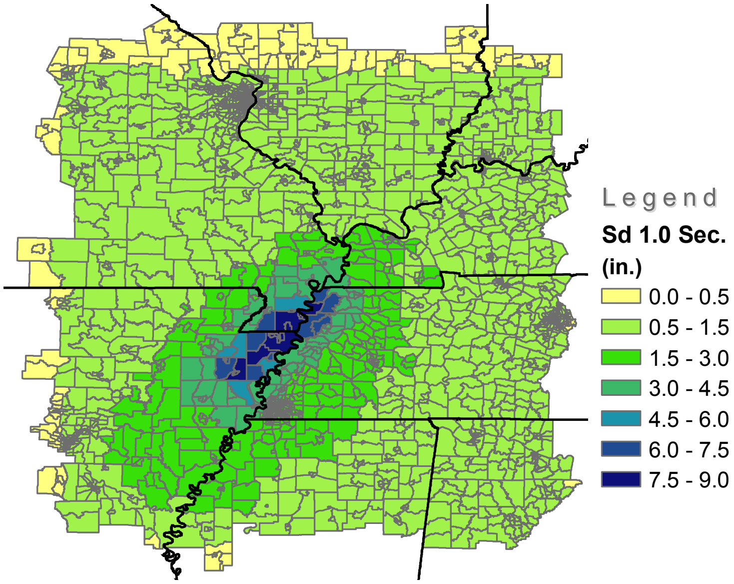


Figure 123: Southwest Epicenter - Improved S_d 1.0 Sec.

Spectral displacements change in the same manner as spectral accelerations with respect to short- and long-period values. Figure 122 & Figure 123 show both spectral displacement values region-wide. The short-period maximum is less with improved site classes, 2.85-inches instead of 4.9-inches. The long-period maximum displacement is greater by 20%; 7.48-inches amplified to 9-inches. Regional long-period displacements increase by roughly 1.0- to 1.5-inches within 300 km of the epicenter.

6.2.3.2 General Building Stock

Updated structural damage patterns for at least moderate damage to light wood frames are used to represent typical structural damage for the three primary building types. The area showing the highest damage probabilities, greater than 70%, is much greater than the default case. In addition, structural damage propagates to the southwest and cuts off in central Arkansas. Structural damage probabilities do not propagate to the east and north experiences minimal probability of reaching this damage state. At least moderate damage patterns for URML buildings are similar to those of W1 buildings, whereas mobile home damage probabilities are confined to a small region in the immediate vicinity of the source (See Figure 124). Both non-structural acceleration and non-structural drift damage patterns for at least moderate damage are similar to W1 damage show above.

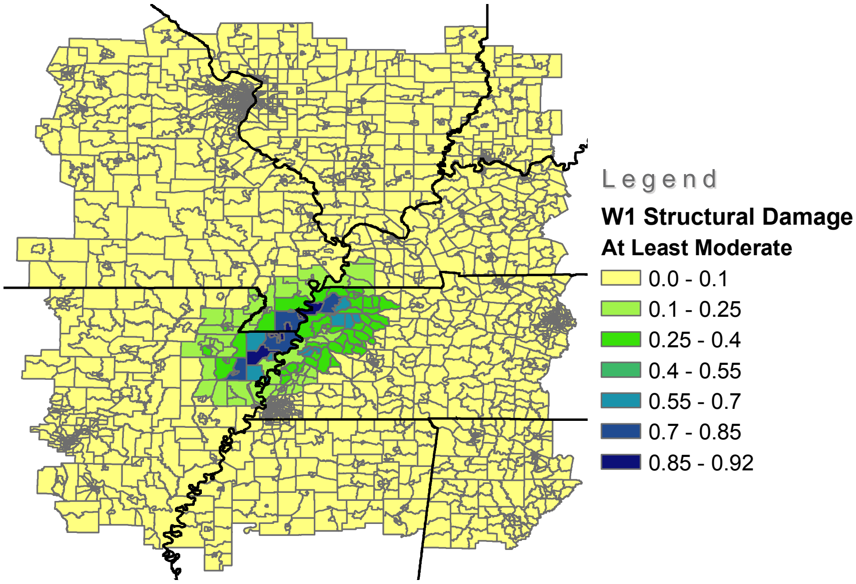


Figure 124: At Least Moderate Structural Damage - W1 – Southwest Improved

The number of damaged buildings in each of the three primary buildings types is displayed in Table 131. The distribution of damage to light wood frames changes slightly from the default case. Here 264 collapses and 4,060 cases of extensive damage are expected which is 100% and 58% larger than default case estimates, respectively. Unreinforced masonry structures show that the occurrence of slight damage increases by 15,000 buildings when site affects are considered. Incidents of moderate damage increase by nearly 13,000 buildings, extensive damage cases increase by 3,500 while collapses increasing by 140%. Cases of moderate damage to mobile homes drops by nearly 15,000 through slightly and moderately damaged structures increase by 8,000 and 13,700 buildings, respectively.

Table 131: Building Damage by Count and Seismic Code Level – Southwest Improved

	Light Wood Frame				
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Buildings	294,618	148,340	41,978	3,649	261
Total Low Code Buildings	2,122,931	124,697	17,747	411	3
Total Buildings	**2417549**	**273037**	**59725**	**4060**	**264**
				Total Number of Building Type:	2754635
%Total Buildings	***87.763%***	***9.912%***	***2.168%***	***0.147%***	***0.010%***
	Unreinforced Masonry				
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Buildings	10594	12541	19609	9015	7935
Total Low Code Buildings	161304	10291	5808	1271	79
Total Pre-Code Buildings	233529	23500	14683	9712	5740
Total Buildings	**405427**	**46332**	**40100**	**19998**	**13754**
				Total Number of Building Type:	525611
%Total Buildings	***77.134%***	***8.815%***	***7.629%***	***3.805%***	***2.617%***
	Mobile Homes				
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Buildings	9184	5994	13238	10664	6270
Total Low Code Buildings	137895	17879	12887	2088	3
Total Pre-Code Buildings	168380	46149	27379	18994	7566
Total Buildings	**315459**	**70022**	**53504**	**31746**	**13839**
				Total Number of Building Type:	484570
%Total Buildings	***65.101%***	***14.450%***	***11.042%***	***6.551%***	***2.856%***

Table 132: Building Damage by State – Southwest Improved

	Low-Code					
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**	**Total**
Alabama	203,832	1,542	120	1	0	**205,496**
Arkansas	309,367	30,961	4,127	263	7	**344,724**
Illinois	329,632	2,895	432	44	1	**333,005**
Indiana	127,541	851	57	1	0	**128,450**
Kentucky	165,232	19,880	5,523	729	21	**191,385**
Mississippi	176,120	46,115	9,222	927	21	**232,406**
Missouri	666,602	2,742	121	1	0	**669,465**
Tennessee	451,667	48,352	17,374	1,993	80	**519,466**
Code Total	**2,429,991**	**153,338**	**36,977**	**3,959**	**130**	**2,624,396**
	Moderate-Code					
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**	**Total**
Alabama	0	0	0	0	0	**0**
Arkansas	49,158	47,479	30,349	10,280	8,114	**145,380**
Illinois	8,974	1,652	379	39	2	**11,045**
Indiana	0	0	0	0	0	**0**
Kentucky	3,895	3,782	1,853	406	93	**10,028**
Mississippi	0	0	0	0	0	**0**
Missouri	61,384	18,168	9,736	3,706	3,090	**96,083**
Tennessee	192,648	97,210	33,879	9,385	3,376	**336,498**
Code Total	**316,059**	**168,291**	**76,197**	**23,814**	**14,674**	**599,035**
Region Total	**2,746,051**	**321,629**	**113,174**	**27,773**	**14,804**	**3,223,431**
% Region Total	***85.190%***	***9.978%***	***3.511%***	***0.862%***	***0.459%***	

Building damage by state is shown in Table 132. The number of low-code collapses increase by roughly 30 across the entire study region. This is due to moderate-code designation being the primary classification in the areas of the most intense shaking. Arkansas and Missouri show substantial collapses of moderate-code buildings with 6,300 and 1,400 more than the Level I cases in each respective state. The frequency of extensive damage to low-code buildings shows an additional 2,000 cases while moderate-code buildings show 6,800 more cases of extensive damage.

General building stock damage is further categorized by general occupancy type and is displayed in Table 133. Incidents of slight damage increase in every category, with the exception of 'educational' buildings. Overall, moderate damage is largely unchanged, though here single family homes comprise a larger percentage of moderately damaged structures. Extensively damaged buildings increase by 50%, while completely damaged buildings triple. "Other residential" buildings experiencing collapse nearly quadruple while commercial collapses increase by roughly 60%.

Table 133: Building Damage by General Occupancy – Southwest Improved

	None		Slight		Moderate		Extensive		Complete	
	Count	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**
Agriculture	2,006	0.06%	80	0.02%	44	0.03%	31	0.05%	45	0.16%
Commercial	27,470	0.87%	3,496	0.89%	3,312	2.11%	1,701	2.95%	803	2.79%
Education	246	0.01%	23	0.01%	17	0.01%	9	0.02%	4	0.01%
Government	1,370	0.04%	156	0.04%	116	0.07%	59	0.10%	34	0.12%
Industrial	4,280	0.13%	640	0.16%	639	0.41%	370	0.64%	192	0.67%
Other Residential	430,092	13.55%	81,325	20.69%	59,065	37.63%	33,681	58.34%	14,958	52.00%
Religion	2,109	0.07%	245	0.06%	190	0.12%	101	0.17%	53	0.18%
Single Family	2,705,995	85.27%	307,094	78.13%	93,570	59.62%	21,784	37.73%	12,677	44.07%
TOTAL	**3,173,568**		**393,059**		**156,953**		**57,736**		**28,766**	

6.2.3.3 Essential Facilities

At least moderate damage to schools is illustrated in Figure 125. The highest damage probabilities extend farther to the south and west in this improved case. In addition, moderate damage probabilities extend even farther southwest to the region boundary, which is not true of the default case. Damage to all essential facilities occurs in similar manners with the greatest probabilities of damage occurring along the Arkansas/Tennessee border and into central Arkansas.

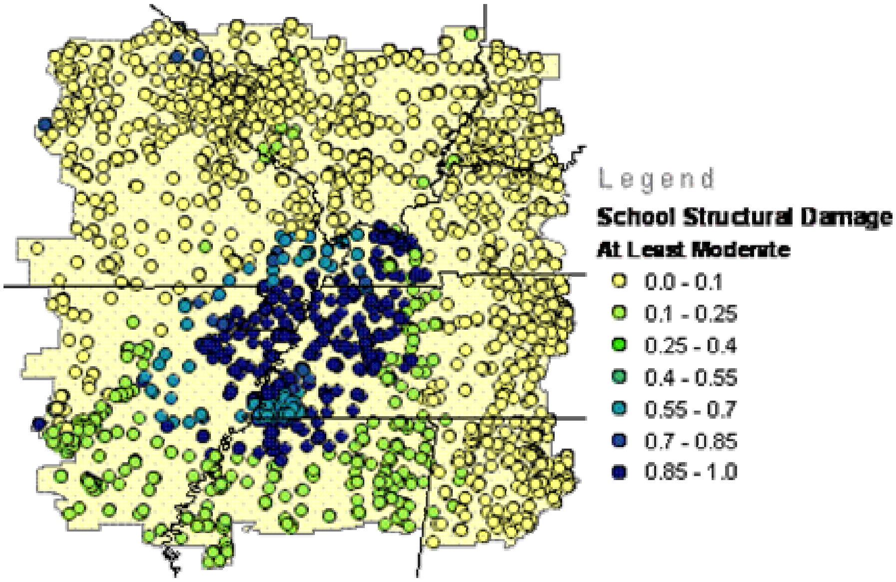


Figure 125: At Least Moderate Damage - Schools – Southwest Improved

Damage to all essential facilities is catalogued in Table 134. Hospitals experience significant changes in damage, with nine more cases of moderate damage and three collapses. An additional 196 fire and 168 police stations see at least moderate damage, while another 424 schools reach this same damage state. The frequency of collapse increases from four to 117 buildings for schools while police stations report nearly 60 additional collapses for each facility type.

Table 134: Essential Facilities Damage – Southwest Improved

		No. of Facilities		
Classification	Total	At Least Moderate Damage >50%	Complete Damage >50%	Functionality >50% at Day 1
Hospitals	308	42	3	200
Schools	4,695	884	117	3,680
EOCs	92	23	1	66
Police Stations	1,207	276	62	888
Fire Stations	1,465	305	62	1,099

Facility functionalities decrease by several percentage points when regional site affects are added. Regionally, only 65% of hospitals are operational the day after an earthquake here, while the default case estimates over 83%. The same is true of fire and police stations where the improved analysis reduces the number of operational facilities by 154 and 118 facilities, respectively. Even after three months fewer facilities are functional, this translates to 49 fewer fire stations, 51 fewer police stations and 82 less schools. These functionalities, as well as those at various other time intervals are shown in Table 135.

Table 135: Essential Facilities Functionalities – Southwest Improved

	Hospitals		Fire Stations		Police Stations		Schools	
	308 Total Strucutres		1465 Total Strucutres		1207 Total Strucutres		4695 Total Strucutres	
	No. Functional	% of Total Functional	No. Functional	% of Total Functional	No. Functional	% of Total Functional	No. Functional	% of Total Functional
Day 1	200	64.94%	1099	75.02%	888	73.57%	3680	78.38%
Day 3	200	64.94%	1099	75.02%	890	73.74%	3682	78.42%
Day 7	266	86.36%	1160	79.18%	931	77.13%	3810	81.15%
Day 14	266	86.36%	1160	79.18%	931	77.13%	3810	81.15%
Day 30	283	91.88%	1369	93.45%	1113	92.21%	4485	95.53%
Day 90	305	99.03%	1401	95.63%	1144	94.78%	4578	97.51%

6.2.3.4 Transportation Systems

Transportation components incur vast amounts of damage over the default case. An additional 800 bridges experience at least moderate damage while the number of highway bridge collapses jumps to 331. As with the previous epicenter analysis, other forms of transportation show marked increases in damage with the incorporation of regional site affects. Moderate damage cases increase by six railway facilities, 15 port facilities and 42 airports. This translates to 7.5% of all regional airports, as oppose to the less than 1% damaged in the default case (See Table 136).

Table 136: Transportation System Damage - Southwest Improved

	No. Facilities		
Classification	Region Total	At Least Moderate Damage	Complete Damage
Highway Bridges	30,314	1,179	331
Railway Bridges	425	4	0
Railway Facilities	393	36	0
Bus Facilities	84	2	0
Ferry Facilities	5	5	5
Port Facilities	691	53	0
Airport Facilities	637	48	1

Table 137: Highway Bridge Functionalities – Southwest Improved

Highway Bridge Fuctionality		
Time	No. Functional	% Total Functional
Day 1	29194	96.31%
Day 3	29280	96.59%
Day 7	29308	96.68%
Day 14	29313	96.70%
Day 30	29319	96.72%
Day 90	29885	98.58%

Table 138: Transportation System Component Losses – Southwest Improved

Component	Loss	% Loss
Highway Bridges	$600,510,000	46.66%
Railway Bridges	$380,000	0.03%
Railway Facilities	$110,290,000	8.57%
Airport Facilities	$364,840,000	28.35%
Bus Facilities	$9,800,000	0.76%
Port Facilities	$195,510,000	15.19%
Ferry Facilities	$5,570,000	0.43%
Total	**$1,286,900,000**	

The result of more bridge damage is a less functional highway systems which results when bridge functionalities decrease. Table 137 details functionality of the regional bridge system. There are approximately 850 fewer functional bridges the day after an earthquake and 800 less after one week. Even after three months nearly 350 additional bridges are not operational.

Transportation losses show increases in all categories, though a substantial amount of additional economic loss is attributed to highway bridges. Approximately \$290 million in additional loss is incurred by highway bridges along. This is a 94% increase in highway bridge losses. Port facilities show an additional \$425 million, while airports contribute another \$227 million. Table 138 shows the loss values for various other transportation system components. Overall transportation losses increase by \$712 million, or 124% of default scenario transportation losses.

6.2.3.5 Utility Systems

Only communication and waste water facilities are affected most by improved site data. Table 139 shows utility damage for the improved case. Waster water facilities show 149 additional incidents of at least moderate damage, while communication facilities experience 90 more cases of the same damage type. All other facility type estimate more than the default case, though no collapses occur with utility facilities for either analysis level.

Table 139: Utility System Damage – Southwest Improved

	# of Facilities				
	Total No.	With at Least Moderate Damage	With Complete Damage	With Functionality > 50%	
				After Day 1	After Day 7
Potable Water	249	19	0	230	245
Waste Water	1,646	180	0	1,280	1,604
Natural Gas	114	6	0	108	114
Oil Systems	49	12	0	37	48
Electric Power	158	17	0	123	156
Communication	940	111	0	910	934

Table 140: Utility Facilities Functionalities – Southwest Improved

	Utility Facilities Functionality						
	Day 1	**Day 3**	**Day 7**	**Day 14**	**Day 30**	**Day 90**	**Total**
Potable Water	226	241	243	243	246	249	**249**
Waste Water	1,319	1,560	1,618	1,618	1,624	1,646	**1,646**
Natural Gas	107	111	112	114	114	114	**114**
Oil Systems	48	48	48	49	49	49	**49**
Electric Power	131	155	157	158	158	158	**158**
Communication	915	931	936	940	940	940	**940**

Changes in utility system functionalities are most prominent the day after an earthquake. Potable water, oil, electric and communication facilities show minor decreases in regional functionalities at Day 1, while the most prominent functional loss is incurred by waste water facilities which report nearly 300 fewer operational facilities the day after the earthquake (See Table 140).

Table 141: Pipeline Damage – Southwest Improved

	Pipeline Length	Number of Leaks	Number of Breaks
Potable Water	500,560	79,350	19,838
Waste Water	300,336	62,759	15,690
Natural Gas	200,224	67,087	16,772
Oil	0	0	0

Table 142: Electric and Potable Water Service Disruptions – Southwest Improved

		No. of Households without Service				
	Total No. Households	Day 1	Day 3	Day 7	Day 30	Day 90
Potable Water	4,236,197	329,000	286,057	231,964	49,865	18,860
Electric Power		404,033	242,848	94,948	19,074	523

Table 143: Utility System Losses – Southwest Improved

Utility System	**Loss**	**% Total**
Potable Water Facility	$439,850,000	5.17%
Potable Water Lines	$357,080,000	4.20%
Waste Water Facility	$6,190,310,000	72.77%
Waste Water Lines	$282,410,000	3.32%
Oil Facilities	$310,000	0.00%
Nautral Gas Facilities	$4,980,000	0.06%
Natural Gas Lines	$301,890,000	3.55%
Electric Systems	$924,460,000	10.87%
Communication	$5,680,000	0.07%
Total	**$8,506,970,000**	

Damage rates to pipelines roughly triple as the frequency of breaks and leaks increase. Again, potable water lines show the greatest number of both breaks and leaks, though the greatest damage rates occur in natural gas lines. The leak rate increases to 0.335 leaks/km from 0.109 leaks/km, while the break rate increases over 200% to 0.084 breaks/km. Break rates for potable and waste water increase by roughly the same margin though the actual rates are less than natural gas damage rates. Table 141 details the damage to regional pipelines.

Further service disruptions are shown in Table 142 for potable water and electricity distribution. The day after the earthquake service outages for potable water and electricity increase by roughly 150,000 and 275,000 outages, respectively. Most notable, however; is the large number of potable water outages after three months. The default case predicts none at this time period, though this improved site class case shows nearly 19,000 outages.

Finally, utility losses increase by approximately 320%. Potable water losses show the greatest increase or nearly $625 million. The waste water subsystem adds $4.9 billion to its damage estimate, or 320% more than the default case. Table 143 shows the remaining systems and their loss values. Overall the utility system show nearly $6.5 billion in additional economic losses.

6.2.3.6 Induced Damage

Fires induced by earthquake damage jump to 155 total ignitions or nearly 100 additional ignitions. Further induced damage is characterized by debris generation, which increases to 12 million tons from the 7 million tons estimated in the default case. This equate to an additional 200,000 truckloads to required to remove the debris, totaling 480,000 truckloads across the entire region.

6.2.3.7 Social and Economic Losses

Shelter requirements go up with the addition of regional site affects in shelter estimates for previous extensions. Both displaced households and temporary housing increase by 40%-45%, with the greatest increases seen in Tennessee. Table 144 highlights both shelter categories by state. Missouri incurs numerous additional housing needs, which is in direct contrast to the negligible needs estimated in the default case. The greater needs in Arkansas and Tennessee, however; add several thousands households and persons to the overall housing need and thus must be considered.

Table 144: Shelter Requirements – Southwest Improved

	Displaced Households	Temporary Housing
Alabama	2	0
Arkansas	9,367	2,750
Illinois	106	33
Indiana	1	0
Kentucky	1,166	336
Mississippi	788	207
Missouri	4,650	1,424
Tennessee	11,434	3,345
Total	***27,514***	***8,095***

The updated soil information produces over 7,400 more casualties, which translates to nearly 55% more than the default case. Table 145 shows casualty estimates for the worst-case at 2 PM. Three-quarters of all casualties are minor injuries, which is true of the default case as well. Fatalities increase by over 450 to 1,107 total fatalities.

Table 145: 2 PM – Southwest Improved

	Level 1	Level 2	Level 3	Level 4
Commercial	8,862	2,298	327	634
Commuting	13	16	29	6
Educational	2,225	596	91	176
Hotels	33	8	1	2
Industrial	1,460	389	56	109
Other-Residential	1,124	269	32	58
Single Family	1,601	423	65	122
TOTAL	**15,318**	**3,999**	**601**	**1,107**

Regional losses increase due to larger amounts of regional damage. Direct losses to buildings alone are illustrated in Table 146. Most states experience major proportional increases building losses, however; Mississippi reports a reduction in building losses of $250 million. Arkansas incurs an additional $2.7 billion while Tennessee adds another $1.2 billion in building losses. Building losses increase by $6.7 billion overall, which indicates a 52% increase in building-related losses from the default case. Transportation losses are estimated at $1.29 billion for the improved site class case, which is a $715 million increase from the default case. Table 147 illustrates the breakdown of transportation losses by state. Again, Arkansas and Tennessee show the most prominent changes in transportation loss value by adding $142 million and $174 million, respectively. Mississippi also contributes an additional $203 million to regional transportation losses. Transportation loss ratios for the southwest rupture scenario with soil amplification are shown in Table 148.

Table 146: Direct Building Losses ($ thousands) – Southwest Improved

	Capital Losses					Income Losses				
	Structural Damage	Non-Structural Damage	Contents Damage	Inventory Loss	Loss Ratio	Relocation Loss	Capital Related Loss	Wages Loss	Rental Income Loss	Total Loss
Alabama	$3,946	$22,809	$11,863	$520	0.12	$56	$676	$1,073	$989	**$41,933**
Arkansas	$845,824	$2,960,873	$1,099,899	$53,819	5.33	$19,147	$173,559	$233,510	$255,950	**$5,642,581**
Illinois	$24,947	$107,738	$54,434	$1,385	0.39	$450	$4,295	$5,142	$6,540	**$204,932**
Indiana	$5,202	$23,771	$14,617	$953	0.10	$55	$582	$738	$969	**$46,886**
Kentucky	$196,808	$542,995	$198,898	$6,783	2.17	$4,563	$56,444	$82,798	$57,716	**$1,147,005**
Mississippi	$231,039	$705,268	$286,634	$17,487	2.48	$5,310	$78,583	$111,602	$75,795	**$1,511,717**
Missouri	$297,649	$972,548	$381,966	$17,067	2.58	$6,176	$45,511	$64,755	$77,896	**$1,863,567**
Tennessee	$1,397,325	$4,459,288	$1,784,278	$70,689	5.44	$33,155	$420,403	$575,945	$457,108	**$9,198,191**
TOTAL	***$3,002,741***	***$9,795,291***	***$3,832,588***	***$168,703***		***$68,912***	***$780,051***	***$1,075,563***	***$932,962***	***$19,656,813***

Table 147: Direct Transportation Losses ($ thousands) – Southwest Improved

	Transportation							
	Highway	Railway	Light Rail	Bus Facility	Ports	Ferries	Airports	Total
Alabama	$2,355	$736	$0	$64	$2,820	$0	$3,365	**$9,340**
Arkansas	$230,710	$21,435	$0	$1,042	$32,972	$0	$118,104	**$404,262**
Illinois	$15,134	$7,050	$0	$1,011	$15,657	$2,420	$31,018	**$72,291**
Indiana	$425	$2,899	$0	$37	$5,451	$0	$8,662	**$17,473**
Kentucky	$11,748	$12,606	$0	$490	$35,730	$1,068	$21,664	**$83,305**
Mississippi	$25,029	$1,973	$0	$566	$5,241	$0	$33,951	**$66,760**
Missouri	$104,549	$25,257	$0	$3,887	$48,097	$1,123	$73,394	**$256,306**
Tennessee	$210,559	$38,708	$0	$2,701	$49,542	$959	$74,683	**$377,152**
TOTAL	***$600,508***	***$110,664***	***$0***	***$9,797***	***$195,509***	***$5,570***	***$364,841***	***$1,286,889***

Table 148: Transportation System Loss Ratios - Southwest Improved

	Loss Ratio
Highway Bridges	2.35%
Railway Bridges	0.71%
Railway Facilities	13.27%
Bus Facilities	10.85%
Ferry Facilities	100.00%
Port Facilities	13.84%
Airport Fcilities	10.84%

Table 149: Direct Utility Losses ($ thousands) – Southwest Improved

	Utility Systems						
	Potable Water	Waste Water	Oil Systems	Natural Gas	Electric Power	Communication	Total
Alabama	$2,756	$17,626	$1	$1,328	$9,417	$38	**$31,165**
Arkansas	$245,782	$2,227,959	$67	$146,752	$343,537	$1,585	**$2,965,682**
Illinois	$47,199	$457,171	$8	$3,341	$56,250	$284	**$564,254**
Indiana	$5,197	$20,327	$9	$774	$8,083	$34	**$34,423**
Kentucky	$51,724	$342,668	$1	$7,273	$59,322	$433	**$461,421**
Mississippi	$20,863	$372,853	$0	$15,302	$59,601	$381	**$469,000**
Missouri	$245,330	$1,491,679	$6	$64,950	$253,786	$962	**$2,056,712**
Tennessee	$178,074	$1,542,443	$219	$67,146	$134,469	$1,962	**$1,924,314**
TOTAL	***$796,926***	***$6,472,726***	***$310***	***$306,866***	***$924,465***	***$5,678***	**$8,506,971**

Utility losses increase by roughly $6.48 billion from the default case, which translates to a 320% change. Table 149 illustrates utility losses by state and shows over half of all utility losses occurring in Arkansas and Missouri. Losses in Arkansas double while Missouri losses jump by nearly $1.9 billion. Also worth noting are utility losses in Tennessee which increase to $1.92 billion from $422 million.

Finally, regional direct losses are calculated and shown in Table 150. Each state shows positive changes in loss value, meaning more loss in each state, with the exception of Mississippi which decreases slightly. The most significant increase occurs in Arkansas, which accounts for 33% of the total increase attributed to the addition of regional site classes. Mississippi is second with $3.88 billion in additional damage and 28% of the regional loss increase. Overall, regional losses increase by approximately $13.9 billion, which still qualifies the southwest epicenter as the worst-case scenario on the New Madrid Fault with $29.5 billion of total direct economic loss.

Also worth noting are regional indirect losses, which show increases of nearly 9% for both jobs and economic loss. The southwest epicenter with improved site class data estimates that 6.16 million jobs are required in the first year following the earthquake, though the default case estimates only 5.64 million jobs. The difference between the default case and the improved case decrease as time passes, and by the fourth year both cases show regional recovery and positive earnings. The indirect economic losses for the improved southwest region are illustrated in Table 151.

Table 150: Direct Economic Losses – Southwest Improved

	Total Loss		
	Improved	**Diff. from Default**	**% Difference**
Alabama	$0.08	$0.04	0.41%
Arkansas	$9.01	$4.65	45.83%
Illinois	$0.84	$0.80	7.90%
Indiana	$0.10	$0.09	0.94%
Kentucky	$1.69	$1.64	16.20%
Mississippi	$2.05	-$0.04	-0.39%
Missouri	$0.42	$0.12	1.22%
Tennessee	$11.50	$2.83	27.90%
Total	**$25.7**	**$10.1**	

	Total Loss		
	Improved	**Diff. from Default**	**% Difference**
Buildings	$19.66	$6.71	48.31%
Transporation	$1.29	$0.71	5.12%
Utilities	$8.51	$6.47	46.57%
Total	**$29.5**	**$13.9**	

Table 151: Indirect Economic Losses – Southwest Improved

	Loss	Total	%
First Year	Employment Impact	6,155,668	206.71
	Income Impact	21,050	14.85
Second Year	Employment Impact	3,671,771	123.30
	Income Impact	17,763	12.53
Third Year	Employment Impact	96,103	3.23
	Income Impact	4,955	3.49
Fourth Year	Employment Impact	5,413	0.18
	Income Impact	-289	-0.20
Fifth Year	Employment Impact	307	0.01
	Income Impact	-584	-0.41
Years 6 to 15	Employment Impact	15	0.00
	Income Impact	-601	-0.42

6.3 Level II Analysis

Level II analysis includes numerous hazard, inventory and fragility improvements. The first of which is the addition of a liquefaction susceptibility map covering most of the study region. As mentioned in previous sections this liquefaction susceptibility map was also developed by FEMA in their baseline study of the New Madrid Seismic Zone (See Figure 16), though this map has been updated since the original baseline study. Some concern on the part of Memphis, Tennessee, area geologists lead to the updating to liquefaction susceptibilities in that area via the development of a new liquefaction proxy (Bausch, November, 2006). Again, developed by Doug Bausch, the new proxy reflects lesser susceptibilities in the Memphis due to the soft upper soils (with NEHRP classification 'D') under bluffs and deeper ground water elevations. The new liquefaction proxy changes site class 'D' from "HIGH" liquefaction susceptibility to "LOW." Further adjustments are made to site class "E' which becomes "MODERATE" as oppose to the "VERY HIGH" classification in the previous liquefaction susceptibility map.

Table 152: Updated Liquefaction Proxy

Soil Type	Description	Liquefaction Susceptibility	HAZUS-MH Value
A	Hard Rock	NONE	0
B	Rock	NONE	0
C	Very Dense Soil & Soft Rock	**NONE**	0
D	Stiff Soils	**LOW**	**2**
E	Soil Soils	**MODERATE**	**3**
F	Soils Requiring Site-Specific Evaluation	VERY HIGH	5

Table 152 illustrates the full updated liquefaction proxy. Regional inventory is improved by adding natural gas and oil distribution and transmission lines. By adding these pipelines HAZUS-MH assumptions and estimations of local pipelines are negated. Lastly, parameterized fragilities developed by the MAE Center are incorporated. These fragilities are applied to all code levels and specific building types in the General Building Stock. Each component is analyzed separately to determine the impact of a single improvement on regional damage and losses. A discussion of each epicenter with the addition of liquefaction susceptibility follows. These analyses build on the Improved

Level I analyses discussed previously, meaning regional site effects are also included in the determination of liquefaction results. Discussions of utility and fragility impacts are included following liquefaction results.

6.3.1 Northeast Epicenter

6.3.1.1 Liquefaction Susceptibility and Permanent Ground Deformation

The addition of liquefaction susceptibility does not change the ground motion parameters presented in the Improved Level I analysis for the northeast extension. All regional PGA, PGV, spectral accelerations and spectral displacements that apply to this Level II analysis of the northeast extension are found in the improved Level I, northeast extension section. Liquefaction susceptibility does, however; generate liquefaction probability, permanent ground deformation due to settlement and permanent ground deformation due to lateral spreading. Regional liquefaction probabilities are illustrated in Figure 126. Regions with liquefaction probabilities greater than 5% correspond to census tracts with a liquefaction susceptibility classification of 'Very High' which is the greatest susceptibility value that HAZUS-MH permits. These census tracts also correspond to locations of softer, highly-variable soil. The northern-most census tracts with

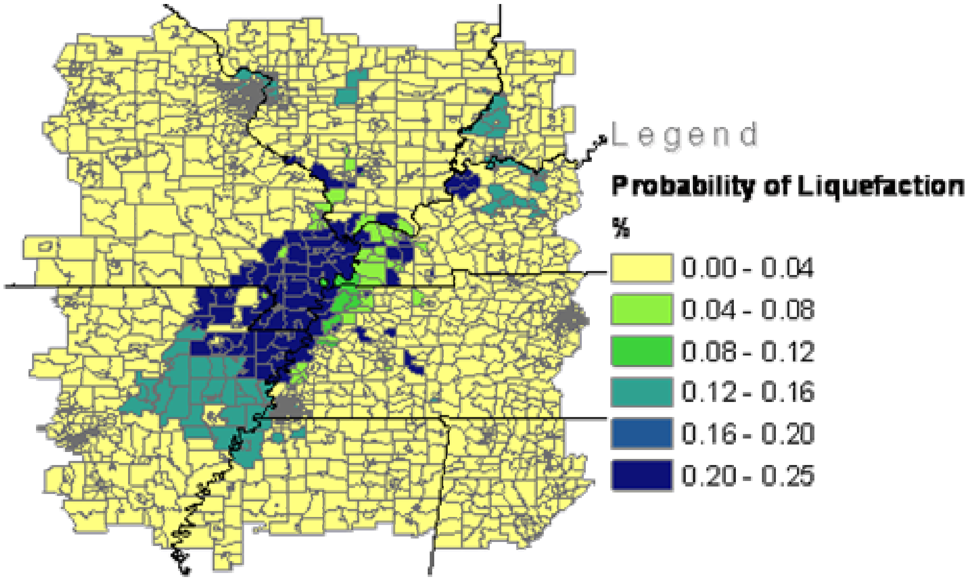


Figure 126: Northeast Epicenter - Probability of Liquefaction

liquefaction probabilities greater than 12% lie along the western side of the Mississippi River while the centrally located census tracts near the northeast extension are located in the Mississippi Embayment. Census tracts in the northeast portion of the study region lie along the Ohio River. The sediment found in these river basins is soft and notorious for liquefying. In that regard the locations with high liquefaction susceptibility and resulting high liquefaction probabilities are regionally appropriate with an epicenter in the north.

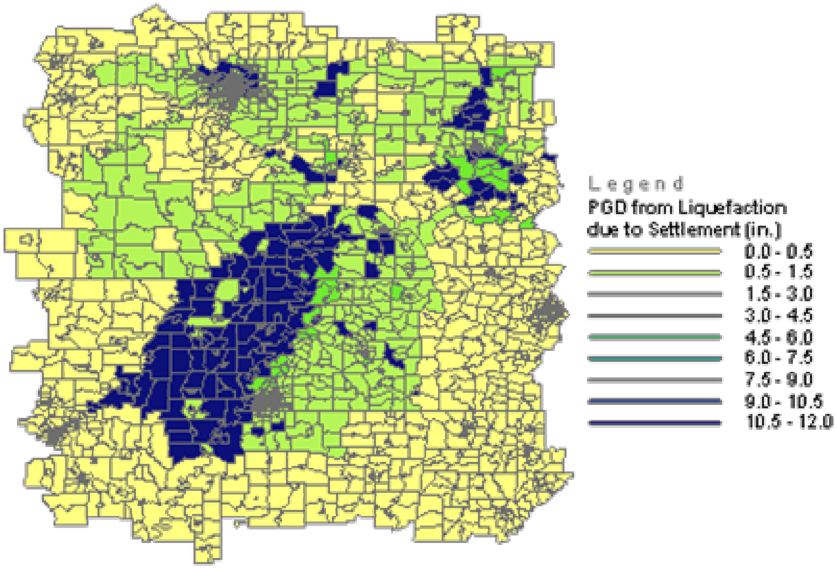


Figure 127: Permanent Ground Deformation due to Settlement (in.) – NE

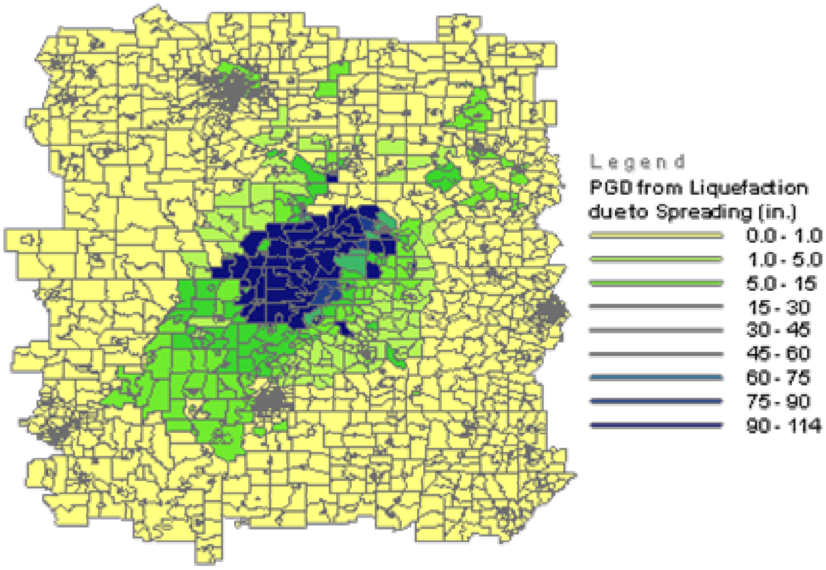


Figure 128: Permanent Ground Deformation due to Lateral Spreading (in.) - NE

Permanent ground deformations due to settlement and lateral spreading from liquefaction are shown in Figure 127 & Figure 128, respectively. The greatest amount of settlement appears where liquefaction susceptibilities are highest. In this case maximum settlements equal 12-inches and are depicted in blue. The remaining regions shown in light green indicate one-inch of settlement. Permanent lateral deformations reach a maximum of 9.5-feet near the epicenter with lateral spreading decreasing to only five-inches along the southern portion of the Mississippi River. Additional census tracts in the north and east show lateral deformations of 2.5- to five-inches in local riverbeds.

6.3.1.2 General Building Stock and Essential Facilities

Distributions of damage for slight, moderate or extensive damage does not change drastically from the improved case for the northeast extension. Light wood frames, URMs and mobile homes show decreases of 5%-10% for all of the damage levels except complete from the improved case. All three primary building types show significant increases in the number of collapsed structures. Light wood frames experience nearly 63,000 more collapses, URMs see 11,400 additional collapses and mobile homes show nearly 10,000 more cases of complete damage. This generates much higher collapse percentages for regional buildings when compared to the improved case. Table 153 illustrates updated damage states for the three primary building types when liquefaction

Table 153: Building Damage by Building Count and Seismic Code Level – NE Level II

	Light Wood Frame				
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Buildings	373202	65914	14087	2155	33495
Total Low Code Buildings	2117904	91103	23836	3200	29747
Total Buildings	**2491106**	**157017**	**37923**	**5355**	**63242**
		Total Number of Building Type:			2754643
%Total Buildings	***90.433%***	***5.700%***	***1.377%***	***0.194%***	***2.296%***
	Unreinforced Masonry				
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Buildings	27307	12451	8031	3176	8677
Total Low Code Buildings	159104	10885	4459	1329	3002
Total Pre-Code Buildings	229798	30448	12741	4945	9144
Total Buildings	**416209**	**53784**	**25231**	**9450**	**20823**
		Total Number of Building Type:			525497
%Total Buildings	***79.203%***	***10.235%***	***4.801%***	***1.798%***	***3.963%***
	Mobile Homes				
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Buildings	11575	9762	11409	4928	7699
Total Low Code Buildings	142051	16469	8204	1895	2139
Total Pre-Code Buildings	169930	50869	27465	10527	9652
Total Buildings	**323556**	**77100**	**47078**	**17350**	**19490**
		Total Number of Building Type:			484574
%Total Buildings	***66.771%***	***15.911%***	***9.715%***	***3.580%***	***4.022%***

susceptibility is added to improved soil information. Light wood frame moderate- and low-code buildings increase by roughly the same margin, with damage split almost evenly between them. The same is true of unreinforced masonry buildings and mobile homes. Most damage states decrease by a small margin (less than 2%), while the incidence of collapse appears to increase exponentially. Of the 11,400 URM collapses low-code collapses go up six-fold and pre-code collapses double. The number of moderate-code collapses increases by over 4,000. Mobile homes at the low-code level show the greatest increase at ten times as many structures collapsing as in the improved case. These three building types incur over 89,000 more completely damaged structures than the improved Level I analysis for this fault extension. It has been shown for previous extensions that square footage damage distributions mimic those seen in building count damage and thus are not discussed or illustrated here.

Table 154: Building Damage by State – NE Level II

	Low-Code					
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**	**Total**
Alabama	204,322	1,103	70	0	0	**205,495**
Arkansas	332,774	10,017	838	12	1,083	**344,724**
Illinois	308,031	13,424	3,189	539	7,821	**333,004**
Indiana	119,393	3,051	251	6	5,749	**128,450**
Kentucky	131,494	23,541	19,888	4,755	11,705	**191,383**
Mississippi	209,484	20,018	1,830	21	1,053	**232,406**
Missouri	656,407	7,572	548	12	4,926	**669,465**
Tennessee	464,971	40,151	10,347	1,255	2,743	**519,467**
Code Total	**2,426,876**	**118,877**	**36,961**	**6,600**	**35,080**	**2,624,394**
	Moderate-Code					
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**	**Total**
Alabama	0	0	0	0	0	**0**
Arkansas	91,409	23,154	8,429	1,523	20,866	**145,381**
Illinois	3,839	1,780	2,240	1,216	1,969	**11,044**
Indiana	0	0	0	0	0	**0**
Kentucky	464	2,380	3,807	1,645	1,732	**10,028**
Mississippi	0	0	0	0	0	**0**
Missouri	47,366	18,427	9,487	3,878	16,925	**96,083**
Tennessee	272,204	43,243	10,082	2,198	8,771	**336,498**
Code Total	**415,282**	**88,984**	**34,045**	**10,460**	**50,263**	**599,034**
Region Total	**2,842,158**	**207,861**	**71,006**	**17,060**	**85,343**	**3,223,428**
% Region Total	***88.172%***	***6.448%***	***2.203%***	***0.529%***	***2.648%***	

State-level damage estimates add another dimension to regional damage values, as various damage levels are assigned frequencies in specific areas. Table 154 divides regional damage by state. Both moderate- and low-code buildings support the previous trend of substantial structural collapse. Moderate-code buildings realize nearly an additional 42,000 collapses while low-code buildings see only 34,500 more cases of complete damage. Roughly over 45 % of these additional collapses occur in Missouri alone, with over 16,000 of the 34,000 new cases of complete damage coming from low-code buildings. Kentucky and Illinois add 11,700 and 9,600 structural failures respectively, with most occurring in low-code buildings. All states experience significant increases in the occurrence of collapse.

Damage to general occupancy classes shows the same trends as damage to building types, though now damage is divided based on building use. Residential collapses increase by over 84,000 buildings, or 440%. Agricultural collapses show an increase of 1132% which equates to only 249 buildings. This is not much when compared to the tens of thousands of additional residential collapses, though this reduction in agricultural capacity may affect regional production. Table 155 highlights the remaining general occupancy categories and the damage predicted for each.

Table 155: Building Damage by General Occupancy Type – NE Level II

	None		Slight		Moderate		Extensive		Complete	
	Count	%	Count	%	Count	%	Count	%	Count	%
Agriculture	1,787	0.05%	82	0.03%	42	0.04%	21	0.06%	271	0.26%
Commercial	29,181	0.89%	3,313	1.14%	2,005	1.78%	928	2.77%	1,355	1.29%
Education	248	0.01%	23	0.01%	13	0.01%	6	0.02%	7	0.01%
Government	1,408	0.04%	149	0.05%	81	0.07%	37	0.11%	59	0.06%
Industrial	4,608	0.14%	650	0.22%	451	0.40%	193	0.58%	218	0.21%
Other Residential	440,095	13.47%	85,539	29.34%	50,282	44.54%	18,314	54.63%	24,891	23.63%
Religion	2,212	0.07%	235	0.08%	117	0.10%	49	0.15%	85	0.08%
Single Family	2,787,277	85.32%	201,523	69.13%	59,910	53.06%	13,976	41.69%	78,434	74.47%
TOTAL	**3,266,816**		**291,514**		**112,901**		**33,524**		**105,320**	

As with general building stock damage patterns, essential facilities damage distributions and locations do not change much with the addition of liquefaction information. There are actually no changes in the number of facilities experiencing moderate damage and collapse (See Table 156). Without any change in regional damage essential facilities functionalities are the same as shown in the improved Level I analysis.

Table 156: Essential Facilities Damage - NE Level II

	No. of Facilities		
Classification	Region Total	At Least Moderate Damage >50%	Complete Damage >50%
Hospitals	308	22	3
Schools	4,695	460	139
EOCs	92	19	10
Police Stations	1,207	177	50
Fire Stations	1,465	218	64

Table 157: Essential Facilities Functionalities - NE Level II

	Hospitals		Fire Stations		Police Stations		Schools	
	308 Total Strucutres		1,465 Total Strucutres		1,207 Total Strucutres		4,695 Total Strucutres	
	No. Functional	% of Total Functional	No. Functional	% of Total Functional	No. Functional	% of Total Functional	No. Functional	% of Total Functional
Day 1	211	68.51%	1,179	80.48%	980	81.19%	4,082	86.94%
Day 3	211	68.51%	1,181	80.61%	981	81.28%	4,082	86.94%
Day 7	286	92.86%	1,247	85.12%	1,030	85.34%	4,235	90.20%
Day 14	286	92.86%	1,247	85.12%	1,030	85.34%	4,235	90.20%
Day 30	290	94.16%	1,354	92.42%	1,127	93.37%	4,472	95.25%
Day 90	304	98.70%	1,389	94.81%	1,149	95.19%	4,525	96.38%

Essential facilities functionalities show minimal change from the values displayed with the addition of liquefaction data. Hospitals indicate virtually no change with the exception to the Day 30 and Day 90 estimations. The remaining three facility types Fire and police stations show approximately a 2% decrease in functionalities in the first few days after the earthquake which drops as time passes. Nearly 100 fewer schools are functional the day after the earthquake though after 90 days this is reduced to only 30 fewer functional schools (See Table 157).

6.3.1.3 Transportation Systems

The transportation damage model is greatly improved with the addition of liquefaction susceptibility information. All roads, runways and railways are now assessable since ground deformations are available. Damage and loss to these components was not considered previously, thus their inclusion now substantially boosts damage and loss estimates. Figure 127, for example, illustrates the regional highway network and damage probabilities for roadways reaching at least moderate damage. The area south of the source which experiences the greatest settlement and lateral spreading shows the greatest likelihood of moderate damage or greater. Damage also extends north along the Mississippi River where liquefaction is likely. The Illinois/Kentucky border shows lesser likelihoods of damage, though these must be considered as well. Railway segments reflect the same damage patterns as highway segment and thus are not illustrated here. At least moderate damage probabilities for airport runways are shown in Figure 130. These paved surfaces show high likelihoods of damage in the same locations as highway segments, though their probabilities are lower. For example, the greatest probability of at least moderate damage for highways is 0.25 while the same location predicts only 0.18 probability of damage for airport runways.

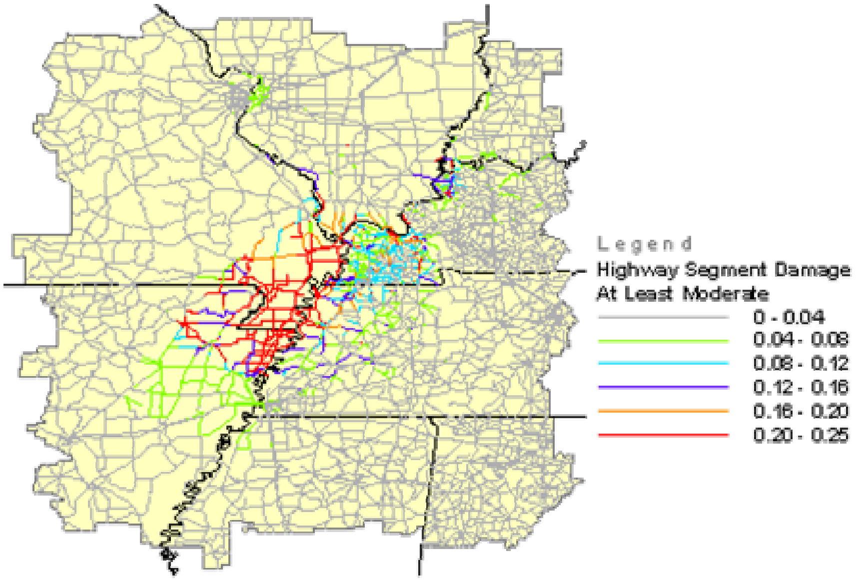


Figure 129: Highway Segment Damage – At Least Moderate – NE Level II

Table 158: Transportation System Damage - NE Level II

	No. Factilities				
	Region Total	At Least Moderate Damage	Complete Damage	Day 1 Functionality	Day 7 Functionality
Highway Bridges	30,314	1,511	443	28,826	29,490
Highway Segments	10,325	0	0	10,314	10,314
Railway Bridges	425	425	8	417	417
Railway Facilities	393	393	55	350	381
Railway Segments	8,885	0	0	8,885	8,885
Bus Facilities	84	7	1	78	83
Ferry Facilities	5	5	5	0	0
Port Facilities	691	138	20	577	652
Airport Facilities	637	43	3	609	629
Airport Runways	720	0	0	720	720

The inclusion of liquefaction contributes to damage gains in other areas of transportation as well. Highway bridges exhibit 680 more instances of moderate damage and nearly 160 more collapses, all in areas of high liquefaction susceptibility. Airports and port facilities show minor damage changes, 12 and 14 more facilities with at least moderate damage, respectively, as shown in Table 158. In terms of functionality, though, bridge functionalities decrease by roughly 800 bridges on a regional level the day after an earthquake. As time passes this margin between the liquefaction and improved Level I analyses decreases, only 200 more bridges after one week. Also, all paved segments are considered functional the day after the earthquake since no paved section is more than 50% likely to incur at least moderate damage. Losses resulting from regional transportation damage are shown in Table 159. The first item to note is the addition of highway, railway and airport runway segments. These new loss categories contribute 63% of all transportation losses, meaning that transportation system losses increase by over 300% from the improved Level I analysis. Further components showing modified loss values include; highway bridges = +$515 million, port facilities = +$34.5 million and airport facilities = +$27 million.

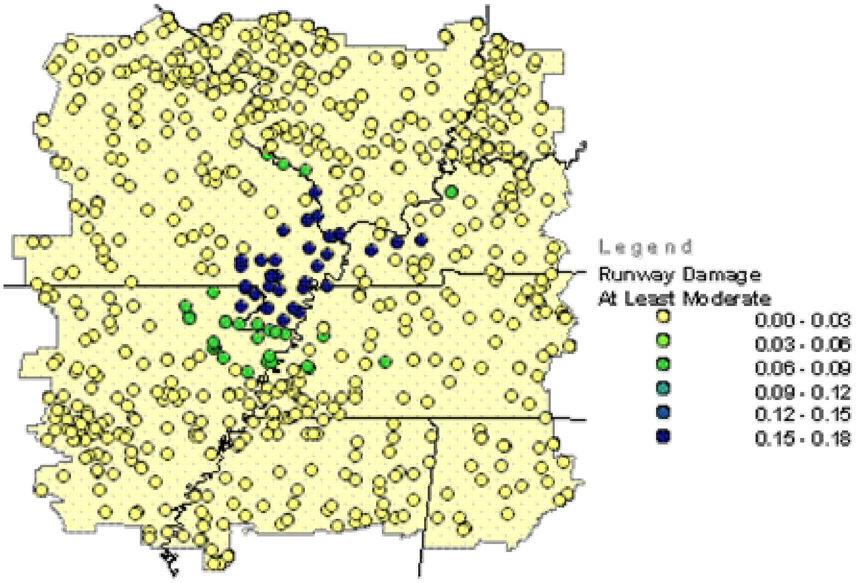


Figure 130: Airport Runway Damage - At Least Moderate – NE Level II

Table 159: Transportation System Losses by Component – Level II NE

Component	Loss	% Loss
Highway Bridges	$945,330,000	19.99%
Highway Segments	$2,518,750,000	53.26%
Railway Bridges	$1,500,000	0.03%
Railway Segments	$167,290,000	3.54%
Railway Facilities	$134,780,000	2.85%
Airport Facilities	$364,140,000	7.70%
Airport Runways	$291,850,000	6.17%
Bus Facilities	$12,350,000	0.26%
Port Facilities	$287,800,000	6.09%
Ferry Facilities	$5,600,000	0.12%
Total	**$4,729,390,000**	

6.3.1.4 Utility Systems

Changes to utility facilities damage are similar to changes shown by essential facilities where no additional structures experience moderate damage or more (See Table 160). Even categories with the greatest inventory, such as waste water facilities and communication facilities, show no increase in damage at the moderate or complete levels. Utility system functionalities show minor changes in facility operation. Communication facilities are slightly less functional the week after an earthquake which will impact the ability to coordinate response efforts. Additionally, more potable and waste water facilities are non-operational, though by only six or seven facilities in the first two weeks after the earthquake (See Table 161).

Table 160: Utility Facilities Damage - NE Level II

	No. Facilities		
Classification	**Region Total**	**At Least Moderate Damage**	**Complete Damage**
Potable Water	249	36	2
Waste Water	1,646	162	13
Natural Gas	114	12	0
Oil Systems	49	1	0
Electric Power	158	16	0
Communication	940	98	3

Table 161: Utility Facilities Functionality - NE Level II

	Utility Facilities Functionality						
	Day 1	**Day 3**	**Day 7**	**Day 14**	**Day 30**	**Day 90**	**Total**
Potable Water	213	232	238	238	245	249	**249**
Waste Water	1,295	1,504	1,577	1,577	1,598	1,639	**1,646**
Natural Gas	102	109	111	114	114	114	**114**
Oil Systems	47	49	49	49	49	49	**49**
Electric Power	130	149	155	158	158	158	**158**
Communication	891	929	933	940	940	940	**940**

Liquefaction susceptibility does affect utility service dramatically even though facilities are not impacted. The improved Level I analysis showed roughly four times as many leaks as breaks, though now breaks greatly outnumber leaks as expressed in Table 162. The number of leaks is reduced by over half of the values delineated in the improved analysis, though with the addition of liquefaction leaks become breaks in pipelines. The number of breaks in potable water pipelines is now over 43,000 which is an increase of 275%. Waste water and natural gas pipeline show similar increases. While potable water systems exhibit the most breaks and leaks the greatest damage rates still belong to natural gas lines. Over 0.107 leaks/km and 0.183 breaks/km are expected for natural gas distribution lines.

Table 162: Pipeline Damage – Level II NE

	Total Pipeline Length (kms)	Number of Leaks	Number of Breaks
Potable Water	500,560	25,240	43,320
Waste Water	300,336	19,962	34,262
Natural Gas	200,224	21,339	36,625
Oil	0	0	0

Disruptions to potable water distribution increase by over 300% the day after the earthquake, while only marginal changes in electric service are predicted. Liquefaction susceptibilities produce 401,000 more potable water outages the day after an earthquake than the improved Level I analysis. Table 163 highlights this change as well as the increase in service disruptions at various other intervals after an earthquake. Another point of concern is the number of households without water after 90 days. The improved Level I analysis estimated that service would be fully restored after three months, while the liquefaction analysis estimates that nearly 36,000 households will still be without water at this time period. Electric outages increase by approximately 2,700 households the day after the earthquake and are nearly twice as much at 30 days after the earthquake, though with regard to the total number of water outages these numbers pale in comparison.

Table 163: Potable Water and Electricity Service Disruptions – Level II NE

	Total No. Households	Day 1	Day 3	Day 7	Day 30	Day 90
Potable Water	4,236,197	530,887	429,928	319,088	167,456	36,131
Electric Power		222,974	151,763	77,044	22,562	271

Table 164: Utility System Losses by Component – Level II NE

Utility System	Loss	% Total
Potable Water Facility	$790,190,000	6.84%
Potable Water Lines	$483,680,000	4.19%
Waste Water Facility	$8,192,710,000	70.92%
Waste Water Lines	$382,550,000	3.31%
Oil Facilities	$200,000	0.00%
Nautral Gas Facilities	$7,940,000	0.07%
Natural Gas Lines	$408,930,000	3.54%
Electric Systems	$1,279,190,000	11.07%
Communication	$6,680,000	0.06%
Total	**$11,552,070,000**	

Liquefaction susceptibilities throughout the region now permit the determination of buried pipeline loss. While pipeline networks are still estimated by HAZUS-MH, losses can be calculated based on these assumptions. Losses for utility system components are then determined based on updated damage to these components, as illustrated in Table 164. The addition of all pipelines contributes another $730 million to total utility system losses. This equates to 6% of all utility losses. Waste water facilities losses increase by nearly $1.1 billion with potable water and electric facilities adding another $108 million and $210 million, respectively. Overall, utility system losses increase by $2.13 billion when liquefaction susceptibility is included.

6.3.1.5 Induced Damage and Social Losses

Induced damage models for fire following the scenario earthquake do not change significantly with the addition of liquefaction, though debris estimates increase. The fire model predicts the same number of ignitions, burnt area and exposed population regardless of liquefaction. Debris estimates nearly double in this Level II analysis as 16 million tons of debris are expected as oppose to only 7 million for the improved Level I scenario. Debris removal now requires 640,000 truckloads, or 360,000 additional truckloads.

Displaced resident estimates are as much as ten times greater in this analysis case than the improved site class scenario. Table 165 shows updated estimates of displaced households and temporary housing requirements. There are over 118,000 displaced households in this earthquake scenario when only 18,500 were expected previously. Furthermore, there are an additional 29,000 cases of temporary housing need than before. The greatest increases are seen in Missouri and Arkansas, though both states experience roughly the same margin of increase. Only 8,345 displaced households are estimated in the improved Level I case for these states, though here there are over 56,000 displaced households. The same follows for temporary housing, where 2,438 cases for temporary housing become 16,759 when liquefaction susceptibilities are added to the study region.

Table 165: Housing Requirements – Level II NE

	Displaced Households	Temporary Housing
Alabama	1	0
Arkansas	22,480	6,400
Illinois	15,334	4,429
Indiana	9,055	2,402
Kentucky	19,951	5,437
Mississippi	1,347	379
Missouri	34,272	10,359
Tennessee	16,302	4,775
Total	***118,742***	***34,181***

Table 166: Casualties - 2 AM – Level II NE

	Level 1	Level 2	Level 3	Level 4
Commercial	181	53	8	16
Commuting	2	3	5	1
Educational	0	0	0	0
Hotels	323	96	14	26
Industrial	220	64	10	19
Other-Residential	7,930	2,117	232	434
Single Family	17,443	4,773	529	988
TOTAL	**26,099**	**7,106**	**798**	**1,484**

Casualty estimates nearly triple with the addition of liquefaction and the worst-case time of day changes as well. The 2 AM estimation is now the greatest at 35,487 casualties. The commuting time, 5 PM, is now second with 31,920 casualties and 2 PM shows the least casualties at 31,915. Table 148 expresses the estimates at the four severity levels for the new worst-case scenario, 2 AM. Each severity level shows roughly the same margin of increase (See Table 166).

6.3.1.6 Economic Losses

Regional building losses are divided by capital and income loss subcomponents in Table 167. Structural damage more than doubles with the inclusion of liquefaction while non-structural damage and contents damage increase 2.5 times. Losses in Arkansas increase by 365%, or $3.9 billion and Indiana exhibits a 1450% higher loss value, which equates to $2.54 billion in additional building damage. Illinois, Kentucky, Missouri and Tennessee show losses doubling from the improved site class case, which equates to roughly $12.2 billion.

Table 167: Direct Building Losses - NE Liquefaction ($ thousands) – Level II NE

	Capital Losses						Income Losses			
	Structural Damage	Non-Structural Damage	Contents Damage	Inventory Loss	Loss Ratio	Relocation Loss	Capital Related Loss	Wages Loss	Rental Income Loss	Total Loss
Alabama	$3,142	$17,072	$8,518	$378	0.08	$39	$498	$741	$753	**$31,141**
Arkansas	$833,902	$2,830,212	$862,087	$33,449	5.83	$18,789	$89,242	$122,193	$235,665	**$5,025,540**
Illinois	$523,069	$2,045,937	$699,953	$12,484	5.49	$10,773	$47,281	$63,289	$136,785	**$3,539,573**
Indiana	$510,749	$1,421,832	$551,360	$46,529	3.13	$6,321	$44,923	$52,653	$83,694	**$2,718,061**
Kentucky	$989,488	$3,493,152	$1,108,174	$30,490	11.73	$21,051	$153,558	$215,729	$265,178	**$6,276,820**
Mississippi	$88,593	$326,769	$129,433	$6,269	1.32	$1,957	$24,348	$36,606	$31,138	**$645,113**
Missouri	$1,166,384	$4,619,210	$1,609,149	$55,033	6.70	$23,597	$178,885	$230,500	$378,366	**$8,261,125**
Tennessee	$999,143	$3,263,385	$1,163,257	$46,947	5.07	$22,409	$251,815	$340,778	$311,749	**$6,399,483**
TOTAL	***$5,114,472***	***$18,017,568***	***$6,131,930***	***$231,580***		***$104,936***	***$790,551***	***$1,062,489***	***$1,443,329***	***$32,896,855***

The addition of segment losses dramatically increase the transportation loss estimate, as discussed earlier. Table 168 illustrates transportation losses by state. Illinois and Tennessee nearly triple their transportation losses while Missouri and Arkansas show much greater losses, between four and six times greater than the improved Level I scenario. Overall, transportation losses increase by $3.28 billion, which is more than twice the transportation estimate in the previous analysis case.

Table 168: Direct Transportation Losses - NE Liquefaction ($ thousands) – Level II NE

	Transportation							
	Highway	Railway	Light Rail	Bus Facility	Ports	Ferries	Airports	Total
Alabama	$2,338	$511	$0	$48	$2,107	$0	$2,514	**$7,518**
Arkansas	$640,138	$26,480	$0	$555	$10,976	$0	$52,248	**$730,397**
Illinois	$436,637	$54,291	$7	$2,549	$52,591	$2,420	$87,568	**$636,063**
Indiana	$46,321	$11,730	$0	$114	$14,208	$0	$20,656	**$93,029**
Kentucky	$716,281	$64,025	$0	$1,339	$98,700	$1,068	$43,152	**$924,565**
Mississippi	$19,656	$734	$0	$136	$2,248	$0	$13,922	**$36,696**
Missouri	$1,048,673	$110,871	$51	$5,947	$81,615	$1,123	$95,450	**$1,343,730**
Tennessee	$554,034	$34,927	$0	$1,664	$25,393	$959	$48,649	**$665,626**
TOTAL	***$3,464,078***	***$303,569***	***$58***	***$12,352***	***$287,838***	***$5,570***	***$364,159***	***$4,437,624***

The loss breakdown for utility systems is shown in Table 169. Most states show moderate gains of roughly 20-25%, though Alabama actually reduces its losses. Reductions like this are uncommon as loss models incorporate more detailed information. These reductions in loss are relatively the same margin for each type of system. Since losses in Alabama are such a small proportion of regional losses the reduction within the state has only a minor affect on regional utility losses.

Table 169: Direct Utility Losses - NE Liquefaction ($ thousands) – Level II NE

	Utility Systems						
	Potable Water	**Waste Water**	**Oil Systems**	**Natural Gas**	**Electric Power**	**Communication**	**Total**
Alabama	$1,228	$8,927	$1	$438	$5,647	$21	**$16,262**
Arkansas	$120,153	$856,254	$22	$88,952	$112,531	$582	**$1,178,494**
Illinois	$289,286	$2,268,137	$44	$41,167	$299,880	$1,355	**$2,899,869**
Indiana	$23,870	$77,932	$30	$6,117	$36,182	$150	**$144,281**
Kentucky	$200,943	$1,169,435	$5	$51,877	$248,982	$1,421	**$1,672,663**
Mississippi	$8,759	$118,926	$0	$5,522	$13,532	$140	**$146,879**
Missouri	$527,366	$3,021,138	$33	$181,663	$497,355	$1,920	**$4,229,475**
Tennessee	$102,268	$1,054,507	$62	$41,135	$65,086	$1,091	**$1,264,149**
TOTAL	***$1,273,873***	***$8,575,256***	***$197***	***$416,871***	***$1,279,195***	***$6,680***	**$11,552,072**

Finally, regional losses are calculated with all infrastructure components. Table 170 illustrates regional losses and loss changes by state. Differences between this analysis case and the improved Level I analysis indicate that nearly 30% of the difference in regional loss occurs in Missouri. Arkansas, Kentucky and Tennessee follow with large proportions of the total regional loss difference. Alabama, however; reduces its total losses by 5%. Losses to buildings account for a smaller percentage of total regional losses due to the inclusion of losses for paved surfaces and pipeline networks. Building losses nearly double while the two remaining categories increase by lesser margins. The earthquake scenario here produces regional losses of $48.9 billion, which is $24.4 billion more than the improved Level I analysis of the same epicenter.

Indirect economic patterns are similar to direct economic loss patterns. Table 171 shows economic losses and regional employment needs for the Level II analysis. Employment needs and indirect economic losses (shown in millions of dollars) are twice the values expected for the improved Level I case. This trend continues throughout the first three years of regional recovery. Indirect economic impacts turn positive in the fourth year, as with the other analysis case, though impacts are still double that of the improved analysis case.

Table 170: Total Direct Economic Losses – Level II NE

	Total Loss		
	Liquefaction	**Diff. from Improved**	**% Difference**
Alabama	$0.05	$0.00	-0.01%
Arkansas	$6.93	$5.01	20.60%
Illinois	$7.08	$2.71	11.13%
Indiana	$2.96	$2.63	10.81%
Kentucky	$8.87	$3.60	14.80%
Mississippi	$0.83	$0.28	1.14%
Missouri	$13.83	$6.80	27.95%
Tennessee	$8.33	$3.30	13.58%
Total	**$48.9**	**$24.3**	

	Total Loss		
	Liquefaction	**Diff. from Improved**	**% Difference**
Buildings	$32.90	$18.92	77.74%
Transporation	$4.44	$3.28	13.48%
Utilities	$11.55	$2.14	8.78%
Total	**$48.9**	**$24.3**	

Table 171: Indirect Economic Loss - NE Liquefaction – Level II NE

	Loss	Total	%
First Year	Employment Impact	-2,825,562	-94.88
	Income Impact	-5,158	-3.64
Second Year	Employment Impact	1,503,010	50.47
	Income Impact	11,069	7.81
Third Year	Employment Impact	168,070	5.64
	Income Impact	8,651	6.10
Fourth Year	Employment Impact	9,466	0.32
	Income Impact	-540	-0.38
Fifth Year	Employment Impact	534	0.02
	Income Impact	-1,057	-0.75
Years 6 to 15	Employment Impact	26	0.00
	Income Impact	-1,086	-0.77

6.3.2 Central Epicenter

6.3.2.1 Liquefaction Susceptibility and Permanent Ground Deformation

As with the northeast extension, central extension ground shaking does not change with the addition of liquefaction susceptibilities. Existing PGAs are used, however; to determine the probability of liquefaction which is shown in Figure 131. The greatest likelihoods of liquefaction still lie along the western edge of the Mississippi River, though these probabilities are still low (< 0.25). The northeast extension shows the highest probabilities confined to the southern-most tip of Illinois and eastern Missouri, while the central extension permits these high probabilities to extend into northeastern Arkansas. Few census tracts in the north and east (northern Kentucky) show more than negligible probabilities of liquefactions as was the case with the northeast epicenter.

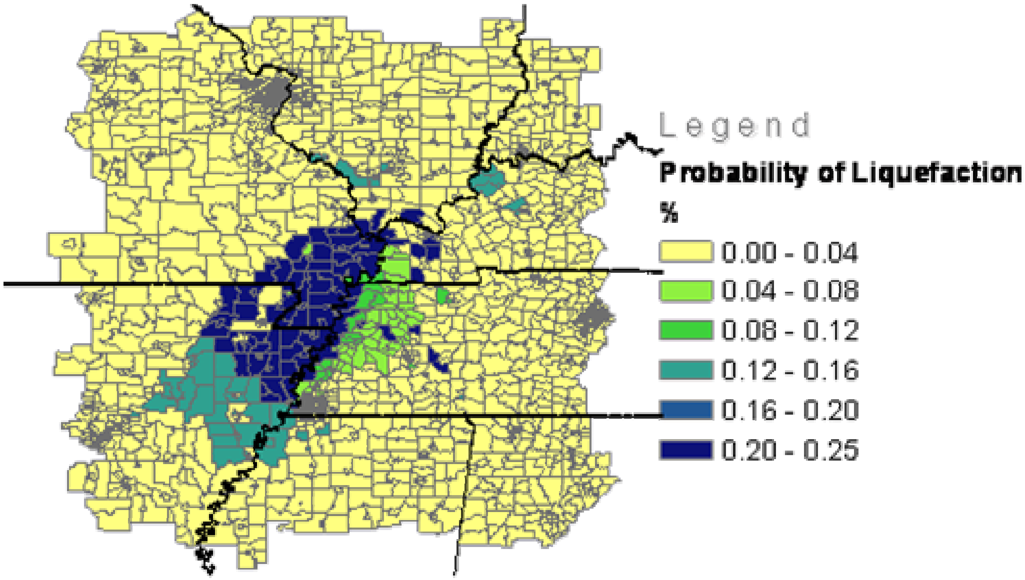


Figure 131: Probability of Liquefaction - Central Epicenter

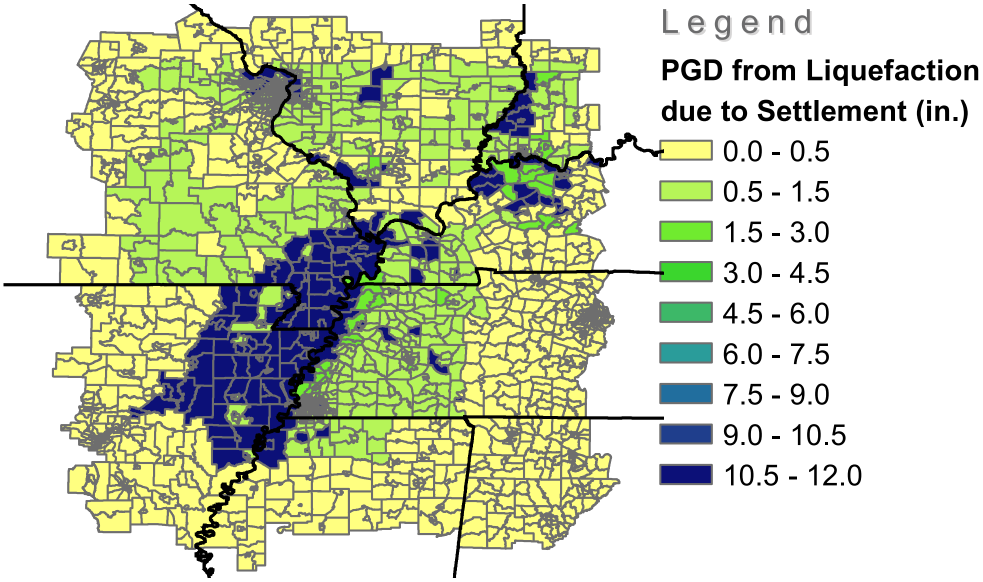


Figure 132: Permanent Ground Deformation due to Settlement (in.) – Level II Central

Permanent ground deformations for vertical settlement and lateral spreading are illustrated in Figure 132 & Figure 133, respectively. The greatest settlements of 12-inches are confined to southeastern Missouri and eastern Arkansas. Vertical deformations of one-inch are experienced all around the Mississippi Embayment

(Mississippi riverbed) and far to the north of the source fault. Lateral spreading reaches a maximum of 114.1-inches nearest the extension in southeastern Missouri. Numerous tracts experience the maximum lateral deformation. It is more common, though, for region census tracts to experience less than an inch, if not zero, lateral deformation. The Mississippi Embayment, however; sees lateral spreading in excess of five-inches, even in more southern census tracts.

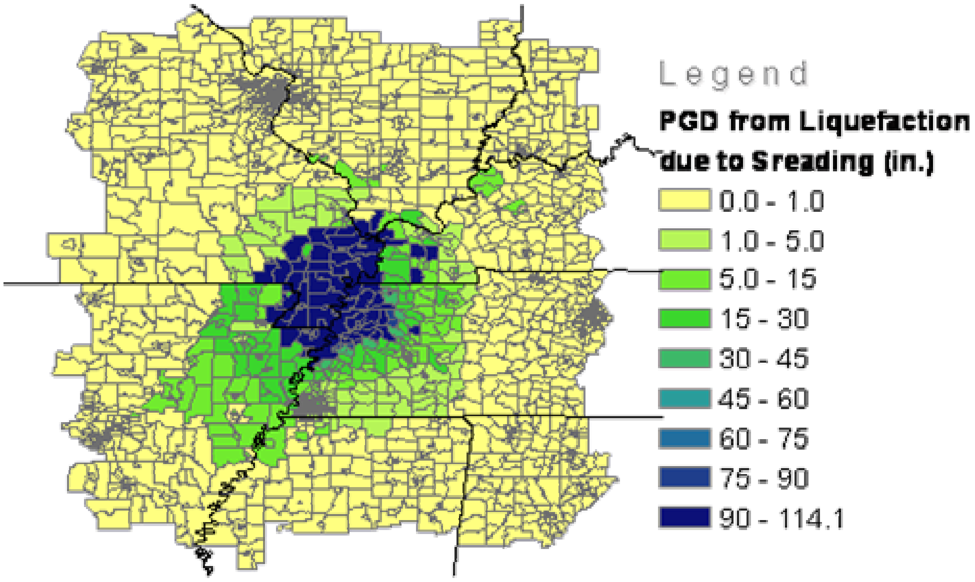


Figure 133: Permanent Ground Deformation due to Lateral Spreading (in.) – Level II Central

6.3.2.2 General Building Stock and Essential Facilities

The improved Level I and analysis for the central source presented numerous figures detailing the probabilities and corresponding distributions for moderate damage or greater. These figures do not change noticeably with the addition of regional liquefaction susceptibilities, though the actual damage count for each HAZUS-MH damage state shows significant changes. Table 172 details the damage distribution of the three primary building types in the study region. The incidence of collapse in light wood frame construction increases by 54,600 cases. Almost 75% of these collapses occur with moderate-code buildings. Cases of moderate and slight damage are reduced by 4,900 and 15,400 structures, respectively. Complete damage to unreinforced masonry buildings increases, from 10,300 to 18,000. Extensive damage cases are cut by 1,600, moderate damage reduced by 2,500 buildings and slight damage cases decrease by over 1,400.

This permits the number of buildings experiencing no damage to increase by 3,000 structures. Mobile homes show an additional 9,000 cases if complete damage, while extensive and moderate damage counts decrease by 2,700 and 3,200, respectively. When these changes are combined with fewer cases of slight damage, the number of mobile homes with no damage actually increases.

Table 172: Building Damage by Count and Seismic Code Level – Level II Central

	Light Wood Frame				
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Buildings	329020	93172	22197	3020	41446
Total Low Code Buildings	2130389	95472	24351	2051	13511
Total Buildings	**2459409**	**188644**	**46548**	**5071**	**54957**
		Total Number of Building Type:			2754629
%Total Buildings	***89.283%***	***6.848%***	***1.690%***	***0.184%***	***1.995%***
	Unreinforced Masonry				
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Buildings	18346	12521	13293	5282	10239
Total Low Code Buildings	163359	8579	4433	1300	1107
Total Pre-Code Buildings	238172	23647	11924	6738	6653
Total Buildings	**419877**	**44747**	**29650**	**13320**	**17999**
		Total Number of Building Type:			525593
%Total Buildings	***79.886%***	***8.514%***	***5.641%***	***2.534%***	***3.425%***
	Mobile Homes				
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Buildings	10100	8721	11918	5790	8853
Total Low Code Buildings	141539	15784	10021	1925	1482
Total Pre-Code Buildings	173110	47027	25574	14061	8679
Total Buildings	**324749**	**71532**	**47513**	**21776**	**19014**
		Total Number of Building Type:			484584
%Total Buildings	***67.016%***	***14.762%***	***9.805%***	***4.494%***	***3.924%***

Damage is also characterized by state and appears in Table 173. As discussed previously, the number of collapses increases, though most of these occur Kentucky and Tennessee with respect to low-code buildings. Kentucky alone goes from only 26 collapses to nearly 5,500. Extensive and moderate damage estimates are reduced by roughly the same margin in every state when compared to the improved analysis. Moderate-code buildings show even more dramatic increases, in particular Arkansas which only incurred 488 cases of complete damage in the improved Level I analysis, though adding liquefaction produces a total of 23,700 collapses. Other drastic increases include collapses in Missouri and Tennessee going up to 16,000 and 19,450, respectively. Cases of complete damage increased six-fold at the moderate-code level, while states with lesser damage change by 10% - 20%.

The final form of building damage predictions are divided by general occupancy. Table 174 illustrates the overwhelming proportion of residential buildings experiencing damage at all levels. Commercial buildings comprise the second largest damage category this is still only 1% - 3% of all damage cases for a given damage state.

Table 173: Building Damage by Building Count and State – Level II Central

	Low-Code					
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**	**Total**
Alabama	203,275	2,035	184	2	0	**205,496**
Arkansas	327,994	13,445	1,173	17	2,094	**344,724**
Illinois	325,716	5,109	770	65	1,345	**333,005**
Indiana	127,321	823	55	1	251	**128,450**
Kentucky	159,222	19,518	6,322	837	5,485	**191,385**
Mississippi	198,494	28,598	3,797	271	1,245	**232,406**
Missouri	665,874	3,388	193	3	7	**669,465**
Tennessee	435,362	47,328	26,793	4,253	5,731	**519,466**
Code Total	**2,443,258**	**120,243**	**39,287**	**5,449**	**16,159**	**2,624,396**
	Moderate-Code					
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**	**Total**
Alabama	0	0	0	0	0	**0**
Arkansas	81,244	26,799	10,812	2,853	23,673	**145,380**
Illinois	7,357	1,919	773	134	862	**11,045**
Indiana	0	0	0	0	0	**0**
Kentucky	2,391	3,631	2,332	617	1,056	**10,028**
Mississippi	0	0	0	0	0	**0**
Missouri	49,676	18,720	7,795	3,876	16,016	**96,083**
Tennessee	219,250	64,430	26,508	6,861	19,451	**336,498**
Code Total	**359,918**	**115,499**	**48,220**	**14,340**	**61,057**	**599,035**
Region Total	**2,803,176**	**235,742**	**87,507**	**19,789**	**77,217**	**3,223,431**
% Region Total	***86.962%***	***7.313%***	***2.715%***	***0.614%***	***2.395%***	

Table 174: Building Damage by General Occupancy – Level II Central

	None		Slight		Moderate		Extensive		Complete	
	Count	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**
Agriculture	2,022	0.06%	80	0.03%	35	0.03%	20	0.05%	49	0.05%
Commercial	28,978	0.89%	3,099	1.01%	2,361	1.87%	1,168	2.80%	1,176	1.26%
Education	251	0.01%	21	0.01%	14	0.01%	7	0.02%	6	0.01%
Government	1,415	0.04%	142	0.05%	84	0.07%	40	0.10%	54	0.06%
Industrial	4,495	0.14%	614	0.20%	495	0.39%	267	0.64%	249	0.27%
Other Residential	441,330	13.62%	80,641	26.17%	51,742	40.89%	23,134	55.52%	22,273	23.87%
Religion	2,188	0.07%	22	0.07%	145	0.11%	68	0.16%	76	0.08%
Single Family	2,759,676	85.17%	223,379	72.48%	71,672	56.64%	16,966	40.72%	69,426	74.41%
TOTAL	**3,240,355**		**307,998**		**126,548**		**41,670**		**93,309**	

The frequency of essential facilities damage does not increase, similar to that shown with the northeast extension at this level of analysis (See Table 175). The lack of change in essential facilities damage translates to no change in regional hospital functionality. Table 176, however; shows the updated functionalities of the remaining essential facility types even though there are no changes as a result of liquefaction susceptibilities.

Table 175: Essential Facilities Damage - Central Level II

	No. Facilities		
	Region Total	At Least Moderate Damage	Complete Damage
Hospitals	308	30	4
Schools	4,695	633	124
EOCs	92	20	4
Police Stations	1,207	221	50
Fire Stations	1,465	253	43

Table 176: Essential Facilities Functionalities – Level II Central

	Hospitals		Fire Stations		Police Stations		Schools	
	308 Total Strucutres		1465 Total Strucutres		1207 Total Strucutres		4695 Total Strucutres	
	No. Functional	% of Total Functional	No. Functional	% of Total Functional	No. Functional	% of Total Functional	No. Functional	% of Total Functional
Day 1	222	72.08%	1132	77.27%	939	77.80%	3949	84.11%
Day 3	222	72.08%	1133	77.34%	940	77.88%	3949	84.11%
Day 7	278	90.26%	1212	82.73%	986	81.69%	4062	86.52%
Day 14	278	90.26%	1212	82.73%	986	81.69%	4062	86.52%
Day 30	287	93.18%	1343	91.67%	1104	91.47%	4423	94.21%
Day 90	302	98.05%	1410	96.25%	1148	95.11%	4537	96.63%

6.3.2.3 Transportation Systems

Damage changes to the transportation system consist of new estimates for highway, railway and airport runway segments. In addition to these new damage calculations permitted by the inclusion of liquefaction susceptibilities, highway bridges incur greater levels of damage. This Level II analysis predicts 1,754 highway bridges realize at least moderate damage with 525 of those being collapse cases as shown in Table 177. This is roughly 80%-85% more than the improved Level I estimates of 934 and 294 bridges, respectively. The number of port and airport facilities experiencing at least moderate damage increase, resulting in 83 ports and 47 airports reaching that damage state. Figure 134 provides a map of at least moderate damage state probabilities for highway segments in the study region. Railway segments also experience damage in this pattern, though maximum

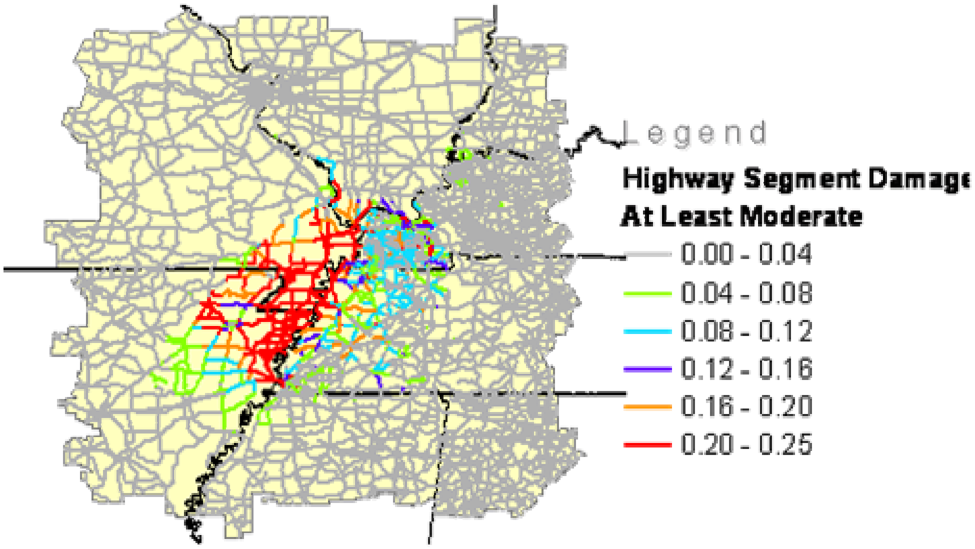


Figure 134: Highway Segments - At Least Moderate Damage – Level II Central

Table 177: Transportation System Damage - Central Level II

	No. Factilities				
	Region Total	At Least Moderate Damage	Complete Damage	Day 1 Functionality	Day 7 Functionality
Highway Bridges	30,314	1,754	525	28,586	29,369
Highway Segments	10,325	0	0	10,314	10,314
Railway Bridges	425	2	0	423	423
Railway Facilities	393	46	0	365	378
Railway Segments	8,885	0	0	8,885	8,885
Bus Facilities	84	7	0	79	82
Ferry Facilities	5	5	5	0	0
Port Facilities	691	83	13	646	663
Airport Facilities	637	47	1	608	629
Airport Runways	720	0	0	720	720

probabilities are slightly lower; 0.20. The highest probabilities of reaching this damage state exist at and southwest of the source fault in the Mississippi Embayment region. Airport runways in the central portion of the study region display the same damage patterns, though the maximum probability of at least moderate damage is just under 0.18.

Transportation components show lower regional functionalities, which is exemplified by bridges in Table 178. The day after the earthquake over 850 fewer bridges are operational which decreases to 180 bridges after a week. This still indicates that over 96% of all regional bridges are operational.

Table 178: Highway Bridge Functionalities – Level II Central

	Highway Bridge Fuctionality	
	No. Functional	% Total Functional
Day 1	28601	94.35%
Day 3	29203	96.34%
Day 7	29369	96.88%
Day 14	29402	96.99%
Day 30	29443	97.13%
Day 90	29711	98.01%

Table 179: Transportation Losses by Component – Level II Central

Component	Loss	% Loss
Highway Bridges	$921,340,000	19.57%
Highway Segments	$2,619,680,000	55.63%
Railway Bridges	$970,000	0.02%
Railway Segments	$162,350,000	3.45%
Railway Facilities	$112,430,000	2.39%
Airport Facilities	$348,040,000	7.39%
Airport Runways	$314,530,000	6.68%
Bus Facilities	$10,730,000	0.23%
Port Facilities	$213,400,000	4.53%
Ferry Facilities	$5,600,000	0.12%
Total	**$4,709,070,000**	

Losses relating to transportation system components are displayed in Table 179. Highway bridge losses double from the improved Level I analysis, and now comprise nearly 20% of new transportation losses. Port and airport facilities show additional losses of approximately $30 million each. The greatest change in transportation loss come from the addition of losses related to paved surfaces and rails. Highway, railway and airport runway segments add $3.1 billion in regional losses, which accounts for a majority of the change in losses to the transportation system. Highway related components comprise the most of the total system losses by far, at nearly 75% of all transportation losses.

6.3.2.4 Utility Systems

Utility facilities do not show any additional damage past that experienced in the improved Level I analysis. This is similar to the damage seen for all the utility facilities in the northeast extension Level II analysis. With damage to utility facilities not changing their functionalities are left unaltered (See Table 180). There are relatively little changes in utility system functionalities, though some type decrease by a few facilities in the first two weeks after the earthquake (See Table 181).

Table 180: Utility Facilities Damage - Central Level II

	No. Facilities		
Classification	**Region Total**	**At Least Moderate Damage**	**Complete Damage**
Potable Water	249	23	3
Waste Water	1,646	163	9
Natural Gas	114	7	0
Oil Systems	49	1	0
Electric Power	158	15	1
Communication	940	100	1

Table 181: Utility Facilities Functionalities - Central Level II

	Utility Facilities Functionality						
	Day 1	**Day 3**	**Day 7**	**Day 14**	**Day 30**	**Day 90**	**Total**
Potable Water	226	240	241	241	245	249	**246**
Waste Water	1,319	1,514	1,602	1,602	1,619	1,643	**1,646**
Natural Gas	107	110	112	114	114	114	**114**
Oil Systems	45	48	48	49	49	49	**49**
Electric Power	131	148	157	158	158	158	**158**
Communication	899	930	932	940	940	940	**940**

Pipeline damage estimates, however; change substantially with the inclusion of liquefaction susceptibility. Thousands of leaks from the improved Level I analysis become breaks and more than triples regional break rates for this source. Potable water pipelines, for example, experience 32,900 more breaks in this liquefaction analysis. The number of leaks in potable water lines drops by roughly 26,600, though. Table 182 displays the regional performance of pipelines for water and natural gas. Natural gas lines continue to have the highest leak and break rates at 0.108 leaks/km and 0.188 breaks/km.

Table 182: Pipeline Damage – Level II Central

	Total Pipeline Length (kms)	Number of Leaks	Number of Breaks
Potable Water	500,560	25,527	44,442
Waste Water	300,336	20,190	35,150
Natural Gas	200,224	21,582	37,574
Oil	0	0	0

Table 183: Potable Water and Electricity Service Disruptions – Level II Central

		No. of Households without Service				
	Total No. Households	Day 1	Day 3	Day 7	Day 30	Day 90
Potable Water	4,236,197	523,044	471,128	391,228	196,125	55,125
Electric Power		230,781	152,668	75,885	22,710	287

Changes to electric and potable water services differ greatly when liquefaction is considered. Electricity outages increase by roughly 3,400 the day after the earthquake in this analysis, though potable water disruptions increase by 393,200. This indicates that day-one water outages increase by over 300%. Table 183 shows the number of service disruptions at various periods after the earthquake. Major differences from the improved site affects analysis are reflected at the 90-day interval. The number of electricity disruptions is unchanged, though potable water outages increase from none to nearly 55,000. This is due entirely to damage calculations for underground pipelines which are only permitted by the determination of settlement and lateral spreading from liquefaction susceptibilities.

Table 184: Utility System Losses by Component – Level II Central

Utility System	Loss	% Total
Potable Water Facility	$571,670,000	5.83%
Potable Water Lines	$496,480,000	5.07%
Waste Water Facility	$6,887,060,000	70.27%
Waste Water Lines	$391,880,000	4.00%
Oil Facilities	$220,000	0.00%
Nautral Gas Facilities	$6,250,000	0.06%
Natural Gas Lines	$418,900,000	4.27%
Electric Systems	$1,023,050,000	10.44%
Communication	$6,030,000	0.06%
Total	**$9,801,540,000**	

Utility losses show updated estimates of pipelines which contributes an additional $760 million to the total estimate of utility system losses. Pipeline losses equate to over 15% of all utility losses. Pipeline and facility loss components for the utility network are delineated in Table 184. Waste water facilities show a $1.19 billion increase, electric and potable water facilities contributing another $190 million and $87 million, respectively. Waste water facilities are still the prominent loss subcomponent with over 70% of all utility losses occurring there.

6.3.2.5 Induced Damage and Social Losses

Fire following earthquake models do not predict significant change from the improved Level I results. The number of estimated ignitions changes from 136 to 139. Greater amounts of collapsed buildings and utility facilities as well as damaged bridges and roads cause debris estimates to increase when liquefaction is considered. Now approximately 15 million tons of debris are expected, as oppose to nine million tons when only site class factors are included. This excess debris requires 600,000 truckloads for adequate removal, which is 240,000 more than the previous analysis case.

The displaced population created by this scenario earthquake is nearly five times greater than estimates for the improved Level I case. Table 185 shows the shelter requirements by state for this hazard. Arkansas exhibits the greatest increase in the number of displaced households; 26,816 up from 1,585. Missouri and Tennessee also experience significant changes as each state sees an additional 14,600 and 25,000 displaced households in this analysis. The greatest need for temporary housing also occurs in the aforementioned states, as well as Kentucky. As with the overall increase in shelter requirements, each of these states incurs at least three times the number of temporary shelter needs in this scenario with liquefaction susceptibility.

Table 185: Shelter Requirements – Level II Central

	Displaced Households	Temporary Housing
Alabama	2	0
Arkansas	26,816	7,713
Illinois	3,321	922
Indiana	385	102
Kentucky	9,723	2,790
Mississippi	1,611	446
Missouri	22,140	6,461
Tennessee	35,546	10,331
Total	***99,544***	***28,765***

Table 186: Casualties - 2 AM – Level II Central

	Level 1	Level 2	Level 3	Level 4
Commercial	150	42	6	12
Commuting	3	3	6	1
Educational	0	0	0	0
Hotels	293	85	12	23
Industrial	221	63	9	18
Other-Residential	6,734	1,739	189	354
Single Family	15,608	4,190	458	856
TOTAL	**23,009**	**6,122**	**680**	**1,264**

As with the northeast epicenter, the worst-case scenario for casualties changes to 2 AM. Casualties for this case are displayed by severity level in Table 186. Nearly 31,100 casualties are expected at this early morning hour, while it is estimated that 2 PM and 5 PM incur 28,688 and 29,196 casualties, respectively. The new worst case of 2 AM shows a 120% increase in the number of casualties, though 2 PM and 5 PM experience only 85% and 105% increases. Rates of change are roughly the same of each severity level, though it is relevant to point out that the previous worst case (2 PM) predicted 798 fatalities, though this analysis now estimates 1,264 fatalities. This scenario is much more dangerous to regional residents as the increase in deaths alone, not including other serious injuries, is 680 cases.

6.3.2.6 Economic Losses

Previous discussions of increased damage levels to this central epicenter event generate much greater economic losses, some of which are expressed in Table 187. Building losses increase substantially due to higher collapse rates, primarily. Structural, non-structural and contents damage more than double when liquefaction is considered. Income losses increase as well, though not as much as capital losses. In the improved Level I analysis Arkansas only incurred $1.6 billion in building losses, though that estimate is multiplied by four, as $6.1 billion of building losses are predicted. Missouri and Tennessee also show significant increases of roughly $2 and $5 billion, respectively. Kentucky adds almost another $1.4 billion, with all other states contributing lesser amounts with the exception of Alabama which does not change. Overall, buildings losses increase by $13.3 billion to $28.7 billion.

Table 187: Direct Building Losses ($ thousands) – Level II Central

	Capital Losses					Income Losses				
	Structural Damage	Non-Structural Damage	Contents Damage	Inventory Loss	Loss Ratio	Relocation Loss	Capital Related Loss	Wages Loss	Rental Income Loss	Total Loss
Alabama	$4,595	$24,972	$12,641	$540	0.14	$67	$709	$1,123	$1,096	**$45,742**
Arkansas	$1,012,532	$3,434,418	$1,048,283	$39,560	7.08	$22,771	$108,291	$148,031	$286,377	**$6,100,264**
Illinois	$123,141	$457,652	$160,849	$3,250	2.01	$2,468	$12,226	$15,497	$30,868	**$805,950**
Indiana	$16,754	$66,940	$28,051	$1,544	0.43	$276	$1,202	$1,611	$3,795	**$120,173**
Kentucky	$459,081	$1,486,194	$480,186	$13,986	5.99	$10,016	$83,408	$116,987	$129,556	**$2,779,415**
Mississippi	$158,286	$540,298	$222,082	$13,017	2.14	$3,423	$49,439	$69,966	$50,208	**$1,106,719**
Missouri	$726,804	$2,511,399	$858,135	$32,833	6.16	$15,363	$87,064	$126,179	$193,497	**$4,551,276**
Tennessee	$2,017,506	$6,981,865	$2,430,543	$91,212	9.64	$45,669	$418,354	$569,572	$617,807	**$13,172,528**
TOTAL	***$4,518,701***	***$15,503,738***	***$5,240,770***	***$195,943***		***$100,052***	***$760,693***	***$1,048,965***	***$1,313,204***	***$28,682,067***

Transportation losses are much higher when liquefaction is considered since paved segments and railways are now assessed damage and loss values. Table 188 shows the updated losses to the transportation system divided by system and state. The highway system shows eight times more loss resulting from highway segment damage and losses. Railways show a similar trend since rail lines are now included. Transportation losses in Arkansas are six times greater here, with $910 million in losses. Kentucky, Missouri and Tennessee also show substantial increases of three to five times the loss values seen in the improved Level I analysis. Overall, transportation losses increase by nearly $3.34 billion to $4.39 billion region-wide.

Table 188: Direct Transportation Losses ($ thousands) – Level II Central

	Transportation							
	Highway	**Railway**	**Light Rail**	**Bus Facility**	**Ports**	**Ferries**	**Airports**	**Total**
Alabama	$2,361	$736	$0	$64	$2,820	$0	$3,365	**$9,347**
Arkansas	$946,405	$45,882	$0	$594	$21,018	$0	$68,850	**$1,082,748**
Illinois	$215,542	$24,867	$0	$1,187	$22,213	$2,420	$41,120	**$307,349**
Indiana	$3,550	$3,139	$0	$37	$5,754	$0	$9,905	**$22,384**
Kentucky	$450,784	$33,823	$0	$683	$48,853	$1,068	$27,148	**$562,359**
Mississippi	$30,425	$1,468	$0	$310	$3,786	$0	$23,571	**$59,559**
Missouri	$1,002,963	$98,922	$0	$4,759	$64,652	$1,123	$96,177	**$1,268,595**
Tennessee	$888,988	$66,914	$0	$3,094	$44,342	$959	$77,902	**$1,082,199**
TOTAL	***$3,541,017***	***$275,750***	***$0***	***$10,727***	***$213,439***	***$5,570***	***$348,037***	***$4,394,540***

Table 189: Direct Utility Losses ($ thousands) – Level II Central

	Utility Systems						
	Potable Water	**Waste Water**	**Oil Systems**	**Natural Gas**	**Electric Power**	**Communication**	**Total**
Alabama	$1,731	$23,353	$1	$462	$9,417	$38	**$35,002**
Arkansas	$169,302	$1,183,603	$23	$118,614	$170,423	$840	**$1,642,805**
Illinois	$92,562	$715,189	$8	$21,384	$105,110	$417	**$934,670**
Indiana	$4,989	$25,960	$9	$384	$8,083	$34	**$39,460**
Kentucky	$96,000	$620,441	$1	$34,543	$113,310	$610	**$864,904**
Mississippi	$10,006	$224,838	$0	$5,831	$34,888	$274	**$275,838**
Missouri	$504,888	$2,497,099	$6	$179,909	$444,406	$1,520	**$3,627,826**
Tennessee	$187,670	$1,988,454	$168	$64,030	$137,413	$2,297	**$2,380,032**
TOTAL	***$1,067,148***	***$7,278,937***	***$216***	***$425,158***	***$1,023,048***	***$6,030***	**$9,800,537**

Utility losses are no exception to the trends shown by building and transportation losses. The improved estimates of pipeline damage and loss contribute significantly to the change in overall utility losses. Table 189 illustrates updated utility losses by subsystem and state. Again, Arkansas shows a large change with nearly an additional $830 million in losses. Tennessee losses increase as well; by over $410 million to $2.38 billion. Overall, utility losses increase by roughly $2.25 billion. Proportionally, utility systems experience the least change of the three infrastructure categories, though this does not diminish the affect of an additional $2.23 billion loss.

Regional losses are displayed in Table 190 by state and major system. Loss increases in Arkansas, Missouri and Tennessee are well documented for the central extension, then it only follows that the majority of new losses are incurred by those states. Over 80% of all additional losses above the improve Level I analysis are incurred by those states. It is also relevant to note that the inclusion of liquefaction actually reduces overall losses in Alabama. Since losses in that state are such a small proportion of regional losses this loss reduction does not impact regional losses substantially. As with the analysis using improved site data only, building losses comprise the majority of regional losses. Transportation and utility losses combine to represent 30% of all regional losses.

Table 190: Total Direct Economic Losses – Level II Central

Total Loss

	Liquefaction	Diff. from Improved	% Difference
Alabama	$0.09	$0.00	-0.01%
Arkansas	$8.83	$6.07	32.05%
Illinois	$2.05	$0.83	4.40%
Indiana	$0.18	$0.08	0.40%
Kentucky	$4.21	$2.04	10.74%
Mississippi	$1.44	$0.32	1.71%
Missouri	$9.45	$3.66	19.30%
Tennessee	$16.63	$5.95	31.41%
Total	**$42.9**	**$19.0**	

Total Loss

	Liquefaction	Diff. from Improved	% Difference
Buildings	$28.68	$13.38	70.60%
Transporation	$4.39	$3.34	17.64%
Utilities	$9.80	$2.23	11.76%
Total	**$42.9**	**$19.0**	

Indirect economic losses also change, and new values are shown in Table 191. Employment needs actually decrease the first year after the earthquake. All income impacts are less than those seen in the improved case. In the second year employment opportunities increase and income impacts are roughly the same as the improved analysis. These changes continue into and past the fourth post-earthquake year when employment needs drop off and economic gains begin.

Table 191: Indirect Economic Losses without Aid – Level II Central

	Loss	Total	%
First Year	Employment Impact	-196,441	-6.60
	Income Impact	2,568	1.81
Second Year	Employment Impact	2,476,680	83.17
	Income Impact	14,444	10.19
Third Year	Employment Impact	145,759	4.89
	Income Impact	7,507	5.30
Fourth Year	Employment Impact	8,209	0.28
	Income Impact	-466	-0.33
Fifth Year	Employment Impact	465	0.02
	Income Impact	-915	-0.65
Years 6 to 15	Employment Impact	23	0.00
	Income Impact	-940	-0.66

6.3.3 Southwest Epicenter

6.3.3.1 Liquefaction Susceptibility and Permanent Ground Deformation

The final epicenter analyzed with regional liquefaction susceptibilities is located in northeastern Arkansas at the southwest tip of the proposed fault. This source fault is situated in the Mississippi Embayment where liquefaction susceptibilities are the greatest. Discussions about previous epicenters state that ground shaking parameters are not altered by the addition of liquefaction susceptibility. The same holds for this epicenter. Probabilities of liquefaction are determined, though, and appear in Figure 135. The area of greatest probability, 0.25, is located around the southwest extension and extends into central Arkansas. This area corresponds to a region with the greatest liquefaction susceptibility, which is then combined with high PGA values in the region which results is high likelihoods over such a large area. Very little liquefaction is expected north of the epicenter where soils are stiffer and less susceptible to liquefaction.

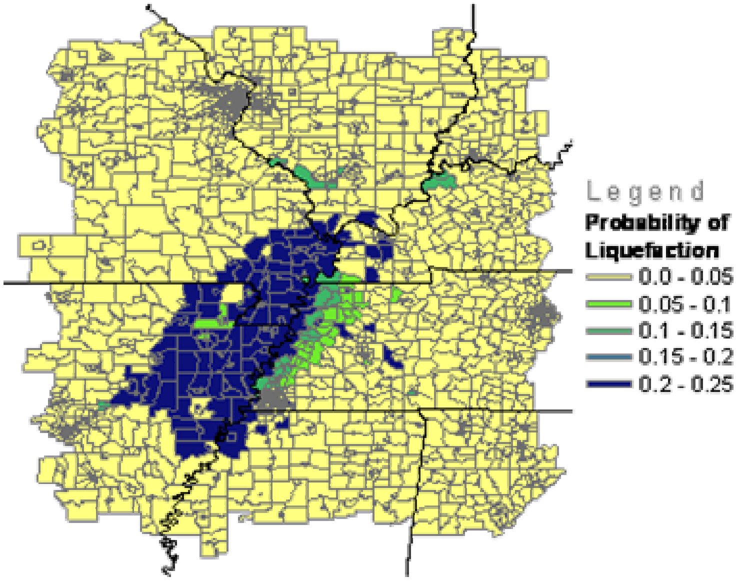


Figure 135: Probability of Liquefaction - SW Epicenter

Further liquefaction-related values, such as vertical and horizontal ground deformations are calculated and the results displayed in Figure 136 & Figure 137. Vertical permanent ground deformation, or settlement, reaches a maximum value of 12-inches in eastern Missouri and Arkansas as well as various census tracts to the north of the source fault. The tracts depicted in light green represent locations where settlement is estimated at one-inch. All other tracts show no settlement. Lateral spreading is confined to the embayment region, with the largest lateral displacements of 114-inches appearing around the fault. Most non-negligible spreading occurs north of the source in northeastern Missouri and almost into southern Illinois. As with other liquefaction parameters, most displacements, lateral and vertical, occur in the embayment region.

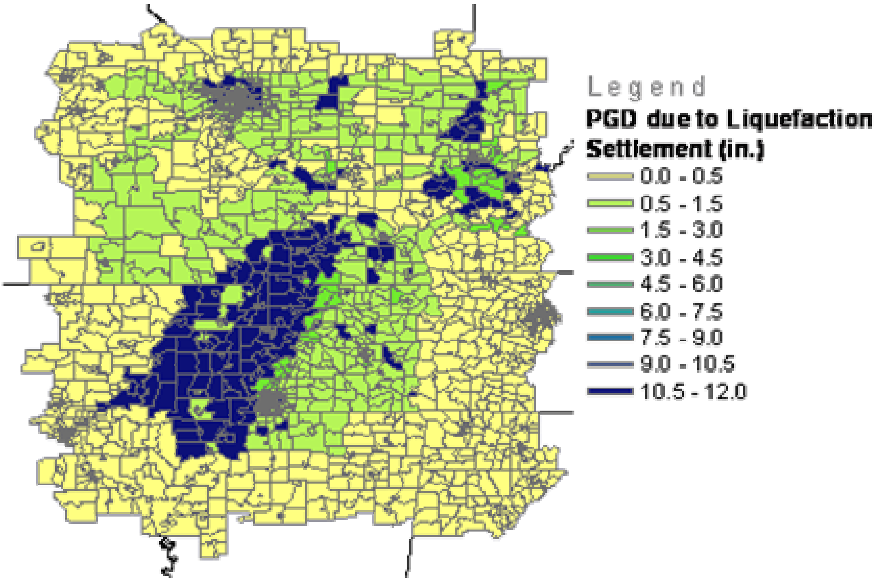


Figure 136: PGD Settlement from Liquefaction (in) – Southwest Epicenter

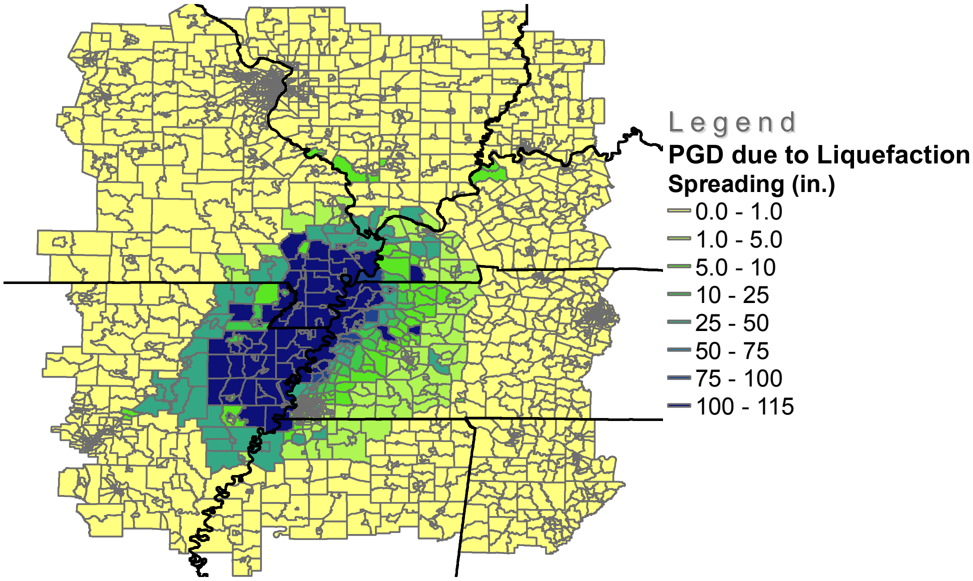


Figure 137: PGD Spreading from Liquefaction (in.) - Southwest Epicenter

6.3.3.2 General Building Stock and Essential Facilities

As with the other extensions damage probabilities remain relatively unaltered for the case of at least moderate damage, though some small differences exist. Figure 138 illustrates the extension of mid-range damage north along the Mississippi River. The improved site case shows a small region around the southwest source fault where all probabilities of at least moderate damage greater than 10% are confined. When liquefaction is considered these mid-range (20% - 40%) probabilities extend north over the highly liquefiable soils in the central portion of the study region. Other building types show similar trends with extended areas of mid-range damage probability, in particular URML and mobile homes.

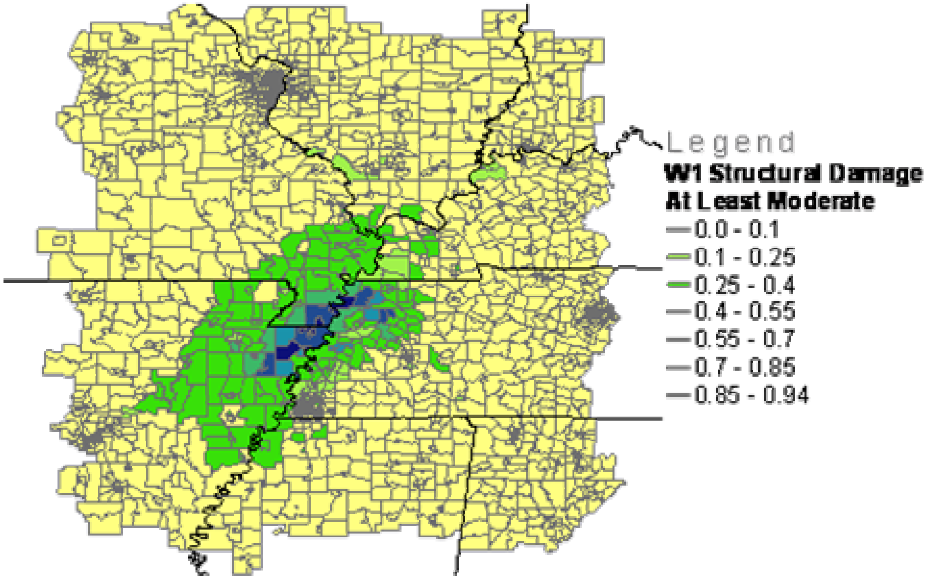


Figure 138: At Least Moderate Structural Damage - W1 – Level II SW

It is well documented through previous extensions that liquefaction multiplies damage estimates, particularly for the complete damage state. The southwest fault is no exception. Table 192 shows the distribution of building damage for the three primary building types. Light wood frames experience a total of 62,600 collapses in comparison to the 264 estimated with improved site data. This is over 235 times as many collapses as the previous analysis case. All other damage states show lower values in this analysis, indicating that most of these losses contribute to the increase in the number of collapses. Unreinforced masonry buildings exhibit a greater number of collapses with liquefaction incorporated, though not to same extent as light wood frames. Just over 8,000 additional URMs are expected to collapse with all other damage states decreasing slightly. The same is true of mobile homes. The number of collapses increases as 8,800 more mobile homes show complete damage in this analysis. Extensive, moderate and slight damage states show fewer occurrences from the improved Level I estimates. The incidence of no damage decreases by roughly 1,000 cases as oppose to the decreasing behavior that is exhibited by unreinforced masonry buildings. Building damage by square footage is not depicted here as damage trends exhibited by building count are only replicated in regional square footage damage estimates. Also note that low-code damage in Indiana is the same as seen with the central extension due to similar shaking in this portion of the study region.

Table 192: Building Damage by Type and Seismic Code Level – Level II SW

	Light Wood Frame				
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Buildings	270773	131394	35125	2969	48584
Total Low Code Buildings	2114648	119670	16879	551	14040
Total Buildings	**2385421**	**251064**	**52004**	**3520**	**62624**
		Total Number of Building Type:			2754633
%Total Buildings	***86.597%***	***9.114%***	***1.888%***	***0.128%***	***2.273%***

	Unreinforced Masonry				
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Buildings	10128	11401	17583	7866	12699
Total Low Code Buildings	161051	10062	5503	1192	967
Total Pre-Code Buildings	233202	23194	13832	8885	8007
Total Buildings	**404381**	**44657**	**36918**	**17943**	**21673**
		Total Number of Building Type:			525572
%Total Buildings	***76.941%***	***8.497%***	***7.024%***	***3.414%***	***4.124%***

	Mobile Homes				
	None	**Slight**	**Moderate**	**Extensive**	**Collapse**
Total Moderate Code Buildings	8909	5447	11325	8769	10920
Total Low Code Buildings	137577	17511	12176	1957	1544
Total Pre-Code Buildings	168124	45904	26658	17545	10203
Total Buildings	**314610**	**68862**	**50159**	**28271**	**22667**
		Total Number of Building Type:			484569
%Total Buildings	***64.926%***	***14.211%***	***10.351%***	***5.834%***	***4.678%***

State-level damage rates change as well, though with behavior like that exhibited in the specific building type analysis. Low-code buildings in Arkansas show nearly 4,300 additional collapses above the improved Level I analysis. Kentucky also shows a substantial increase in the occurrence of collapse from 21 to over 40,000. Moderate-code buildings in Arkansas also exhibit the much greater damage as over 33,000 buildings are expected to collapse instead of roughly 8,000 as in the previous analysis case. Tennessee's moderate-code buildings exhibit seven times as many collapses in this liquefaction analysis, contributing to the overwhelming increase in complete building damage. Table 193 shows this as well as all other damage states. Damage by general occupancy is shown in Table 194 and residential types of construction show the greatest percentage of damage for each damage state. Collapses to residential buildings increase by nearly 78,900 which is far more than any other general occupancy type.

Table 193: Building Damage by State – Level II SW

	Low-Code					
	None	Slight	Moderate	Extensive	Collapse	Total
Alabama	203832	1542	120	1	0	205495
Arkansas	306611	29819	3795	225	4275	344725
Illinois	328598	2667	360	35	1344	333004
Indiana	127321	823	55	1	251	128451
Kentucky	163220	18356	5024	698	4087	191385
Mississippi	174892	44951	8898	932	2733	232406
Missouri	666602	2742	121	1	0	669466
Tennessee	450046	46803	16716	1998	3904	519467
Code Total	**2421122**	**147703**	**35089**	**3891**	**16594**	**2624399**
	Moderate-Code					
	None	Slight	Moderate	Extensive	Collapse	Total
Alabama	0	0	0	0	0	0
Arkansas	40624	38935	24445	8131	33244	145379
Illinois	8389	1488	325	32	811	11045
Indiana	0	0	0	0	0	0
Kentucky	3575	3529	1725	378	822	10029
Mississippi	0	0	0	0	0	0
Missouri	56647	14956	7513	2820	14148	96084
Tennessee	182118	90639	31255	8660	23826	336498
Code Total	**291353**	**149547**	**65263**	**20021**	**72851**	**599035**
Region Total	**2712475**	**297250**	**100352**	**23912**	**89445**	**3223434**
% Region Total	***84.149%***	***9.222%***	***3.113%***	***0.742%***	***2.775%***	

Table 194: Building Damage by General Occupancy – Level II SW

	None		Slight		Moderate		Extensive		Complete	
	Count	%	Count	%	Count	%	Count	%	Count	%
Agriculture	2,004	0.06%	77	0.02%	40	0.03%	27	0.05%	57	0.05%
Commercial	27,364	0.87%	3,342	0.91%	3,079	2.16%	1,559	3.03%	1,437	1.32%
Education	245	0.01%	22	0.01%	16	0.01%	8	0.02%	7	0.01%
Government	1,366	0.04%	151	0.04%	106	0.07%	52	0.10%	60	0.06%
Industrial	4,267	0.14%	620	0.17%	600	0.42%	338	0.66%	295	0.27%
Other Residential	428,076	13.64%	79,324	21.55%	55,159	38.71%	30,021	58.26%	26,541	24.45%
Religion	2,097	0.07%	235	0.06%	178	0.12%	94	0.18%	94	0.09%
Single Family	2,673,965	85.17%	284,332	77.24%	83,319	58.47%	19,427	37.70%	80,077	73.76%
TOTAL	**3,139,384**		**368,103**		**142,497**		**51,526**		**108,568**	

Damage to essential facilities is left unchanged as is shown in Table 195. This replicates behavior illustrated by the previous two fault extensions. The number of functional essential facilities within the study region does change in the first week following the earthquake as is illustrated in Table 196. At later time periods, however, recovery slows and fewer essential facilities throughout the region are operational with the addition of liquefaction, though this reduction in minor.

Table 195: Essential Facilities Damage - Level II SW

	No. of Facilities		
Classification	Region Total	At Least Moderate Damage >50%	Complete Damage >50%
Hospitals	308	42	3
Schools	4,695	885	117
EOCs	92	23	1
Police Stations	1,207	276	62
Fire Stations	1,465	305	62

Table 196: Essential Facilities Functionalities - Level II SW

	Hospitals		Fire Stations		Police Stations		Schools	
	308 Total Strucutres		1,465 Total Strucutres		1,207 Total Strucutres		4,695 Total Strucutres	
	No. Functional	% of Total Functional	No. Functional	% of Total Functional	No. Functional	% of Total Functional	No. Functional	% of Total Functional
Day 1	200	64.94%	1,076	73.45%	868	71.91%	3,648	77.70%
Day 3	200	64.94%	1,076	73.45%	870	72.08%	3,650	77.74%
Day 7	266	86.36%	1,160	79.18%	931	77.13%	3,810	81.15%
Day 14	266	86.36%	1,160	79.18%	931	77.13%	3,810	81.15%
Day 30	283	91.88%	1,312	89.56%	1,075	89.06%	4,399	93.70%
Day 90	303	98.38%	1,381	94.27%	1,125	93.21%	4,522	96.32%

6.3.3.3 Transportation Systems

Changes to transportation system damage occur with highway bridges primarily. Over 800 additional bridges experience at least moderate damage and another 200 collapses. Further damage occurs to railway facilities which increase to 85 facilities with moderate damage instead of just 36 as shown in Table 197. Port facilities show 56 more instances of moderate damage for a total of 109 facilities, while airport facilities with at least moderate damage increases to 14.

Table 197: Transportation System Damage - Level II SW

	No. Factilities				
	Region Total	At Least Moderate Damage	Complete Damage	Day 1 Functionality	Day 7 Functionality
Highway Bridges	30,314	1,987	530	28,356	29,142
Highway Segments	10,325	0	0	10,314	10,314
Railway Bridges	425	9	0	416	421
Railway Facilities	393	85	0	358	376
Railway Segments	8,885	0	0	8,885	8,885
Bus Facilities	84	5	1	82	83
Ferry Facilities	5	5	5	0	0
Port Facilities	691	109	14	638	660
Airport Facilities	637	64	8	596	624
Airport Runways	720	0	0	720	720

The regional functionality of highway bridges decreases much the same as the previous epicenter when liquefaction is added. The day after the earthquake roughly 800 fewer bridges are operational. Table 198 shows the functionality of regional bridges up to three months after the earthquake. Three months after the earthquake only 100 fewer bridges are functional, though these bridges are located closest to the epicenter further diminishing the capacity of that region's transportation network.

Table 198: Highway Bridge Functionality – Level II SW

	Highway Bridge Fuctionality	
	No. Functional	% Total Functional
Day 1	28,372	93.59%
Day 3	29,019	95.73%
Day 7	29,142	96.13%
Day 14	29,182	96.27%
Day 30	29,210	96.36%
Day 90	29,767	98.20%

The highway network shows the greatest probability of damage in northeastern Missouri, nearest the epicenter. Figure 139 illustrates the probability distribution for the case of at least moderate damage. The greatest probability of damage is only 0.25 (depicted in red) though this extends of over a large area. Damage probabilities greater than 5% do not extend much outside Arkansas, indicating that the greatest damage, and losses, will occur in this area. Damage to railway lines occur in the same manner, though the maximum probability of damage is roughly 0.20. Airport runways also experience damage in this fashion, as they too are paved surfaces.

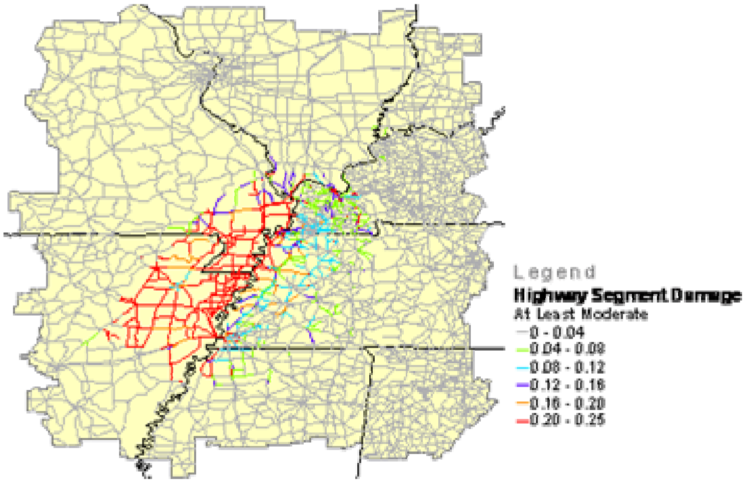


Figure 139: At Least Moderate Damage - Highway Segments – Level II SW

Losses related to various transportation components are delineated in Table 199. Loss categories are added for highway segments, railway segments and airport runways. These new categories alone total $1.68 billion, which equates to over 30% of all transportation losses. Highway bridge loss increases from $601 million to $2.98 billion and railway bridge loss more than doubles with the addition of liquefaction. Airport facilities incur an additional $36 million, thus bus and ferry facilities remain unchanged. The highway system, however, still maintains the greatest percentage of transportation losses at 75%.

Table 199: Transportation Losses by Component – Level II SW

Component	Loss	% Loss
Highway Bridges	$2,980,840,000	54.84%
Highway Segments	$1,087,900,000	20.02%
Railway Bridges	$1,070,000	0.02%
Railway Segments	$201,450,000	3.71%
Railway Facilities	$128,360,000	2.36%
Airport Facilities	$400,670,000	7.37%
Airport Runways	$390,610,000	7.19%
Bus Facilities	$10,530,000	0.19%
Port Facilities	$228,240,000	4.20%
Ferry Facilities	$5,570,000	0.10%
Total	**$5,435,240,000**	

6.3.3.4 Utility Systems

Utility facilities do not experience significant increases in moderate damage and do not incur any collapses even with the addition of liquefaction (See Table 200). In addition, changes to utility facility functionalities are still roughly the same as those displayed in the improved Level I case, as is shown in Table 201.

Damage to pipeline is very different from estimates shown in the previous analysis case. The number of leaks for each type of pipelines is reduced by half, though the amount of breaks increases by roughly that same amount. Table 202 illustrates the occurrence of leaks and breaks for this scenario event. As in the previous analysis case potable water lines show the greatest number of leaks and breaks at 39,540 and 58,974, respectively. Natural gas lines still hold the greatest leak rate of 0.167 leaks/km, which is approximately half of the leak rate determined with the improved site factor case. Break rate is also greatest with natural gas lines with an estimated 0.249 breaks/km. This is roughly three times more than the previous analysis case where the break rate for natural gas pipelines was 0.084 breaks/km.

Table 200: Utility Facilities Damage - Level II SW

Classification	No. Facilities		
	Region Total	At Least Moderate Damage	Complete Damage
Potable Water	249	19	3
Waste Water	1,646	180	16
Natural Gas	114	6	0
Oil Systems	49	12	0
Electric Power	158	17	2
Communication	940	111	6

Table 201: Utility Facilities Functionality - Level II SW

	Utility Facilities Functionality						
	Day 1	Day 3	Day 7	Day 14	Day 30	Day 90	Total
Potable Water	230	240	244	244	245	249	**249**
Waste Water	1,280	1,484	1,587	1,590	1,605	1,636	**1,646**
Natural Gas	108	111	114	114	114	114	**114**
Oil Systems	35	44	47	49	49	49	**49**
Electric Power	123	148	155	157	158	158	**158**
Communication	896	926	929	940	940	940	**940**

Table 202: Pipeline Damage – Level II SW

	Total Pipeline Length (kms)	Number of Leaks	Number of Breaks
Potable Water	500,560	39,540	58,974
Waste Water	300,336	31,273	46,643
Natural Gas	200,224	33,430	49,860
Oil	0	0	0

Table 203: Potable Water and Electricity Service Disruptions – Level II SW

		No. of Households without Service				
	Total No. Households	Day 1	Day 3	Day 7	Day 30	Day 90
Potable Water	4,238,197	691,487	667,700	628,100	359,277	119,978
Electric Power		409,466	256,907	117,481	33,448	523

Service disruptions increase for potable water distribution though leaves electric service much the same as in the improved Level I analysis. Table 203 displays the number of service outages at various periods after the scenario earthquake. The number of potable water disruptions more than doubles the day after the earthquake and this ratio only increases until the last interval; 90 days. The improved site analysis estimated all potable water service be operational within three months after the earthquake, though the addition of liquefaction susceptibility brings that number to nearly 120,000 outages. Regional electric service incurs approximately, 5,400 additional disruptions the day after the earthquake, only to show a greater increase of 14,000 outages after three days. This margin over the improved case keeps increasing until one month after the scenario earthquake. By the three month interval, however; service disruptions are equal to those seen in the improved Level I analysis.

Losses to the utility system increase due to the inclusion of pipeline losses which are made possible by the incorporation of liquefaction susceptibility. Pipeline losses alone account for $1.76 billion of utility losses, which equates to 16% of all utility system losses. Table 204 highlights these loss values as well as the loss incurred by all other utility subsystems. An additional $1.24 billion in loss is attributed to waste water facilities, which still maintain the highest percentage of total utility losses. Natural gas and electric components show approximately $250 million in additional loss each, contributing to the overall loss increase.

Table 204: Utility System Losses by Component – Level II SW

Utility System	Loss	% Total
Potable Water Facility	$516,050,000	4.68%
Potable Water Lines	$668,820,000	6.06%
Waste Water Facility	$7,605,070,000	68.92%
Waste Water Lines	$528,980,000	4.79%
Oil Facilities	$360,000	0.00%
Nautral Gas Facilities	$6,010,000	0.05%
Natural Gas Lines	$565,460,000	5.12%
Electric Systems	$1,137,440,000	10.31%
Communication	$6,560,000	0.06%
Total	**$11,034,750,000**	

6.3.3.5 Induced Damage and Social Losses

Shelter requirements roughly quadruple, with over 144,000 displaced households and 33,000 temporary housing needs. The majority of this housing need occur in Arkansas and Tennessee as is shown in Table 205. Memphis, Tennessee is within tens of kilometers of the southwest source and is likely to sustain significant damage to its residential building infrastructure leaving many citizens without a place to live. Missouri also shows nearly 15,000 additional displaced households and 4,300 temporary housing requirements. Overall, however; over 87,000 more households are displaced and 25,000 additional temporary housing spaces.

Table 205: Housing Requirements – Level II SW

	Displaced Households	Temporary Housing
Alabama	2	0
Arkansas	39,183	11,392
Illinois	3,211	892
Indiana	385	102
Kentucky	7,391	2,133
Mississippi	3,995	1,083
Missouri	19,640	5,767
Tennessee	40,894	12,004
Total	***114,701***	***33,373***

As with the central epicenter, the addition of liquefaction susceptibilities does not change the number of fire ignitions following the earthquake significantly. Debris generation does increase, however; from 12 million tons to 18 million tons. Additional truckloads are required to remove the extra debris. Additional debris requires 240,000 truckloads, for a total of 720,000 truckloads.

Table 206: Casualties - 2 AM – Level II SW

	Level 1	Level 2	Level 3	Level 4
Commercial	191	53	8	15
Commuting	3	4	7	1
Educational	0	0	0	0
Hotels	392	111	16	30
Industrial	283	82	12	24
Other-Residential	8,057	2,076	227	426
Single Family	17,996	4,819	529	987
TOTAL	**26,922**	**7,145**	**799**	**1,483**

The northeast and central extensions established a new time of day for the worst-case casualty scenario as does the southwest source, 2 AM. Table 206 delineates the numbers and severities of casualties at this time of day. A total of 36,352 casualties are expected at 2 PM, while 2 PM and 5 PM are estimated to create 35,334 and 35,295 casualties, respectively. This indicates that adding liquefaction susceptibility information adds roughly 15,000 casualties to the study region, with nearly 400 of those being additional deaths. While each severity level increases by roughly the same margin it is still vital to keep in mind that this worst case scenario generates nearly 800 severe injuries and 1,500 deaths which might be reduced if regional infrastructures are strengthened.

6.3.3.6 Economic Losses

Building losses for the entire study region are delineated by type and state in Table 207. Structural, non-structural and contents damage nearly double only with the addition of liquefaction susceptibility. All income losses increase, though by much smaller margins. Losses in Arkansas increase by nearly $5 billion while another $5.7 billion of additional building loss occurs in Tennessee. All other states experience increased building losses, with the exception Alabama which remains unchanged. Total building losses increase by $14.7 billion to reach $34.4 billion regionally.

Transportation losses for components of the system were discussed earlier, though state losses have not and appear in Table 208. Losses in Arkansas alone increase by $1.4 billion, which equates to nearly 370% more than the improved Level I analysis. Missouri sees an additional $880 million of loss while Tennessee losses jump to $1.14 billion in losses state-wide. As with building losses, Alabama does not incur additional losses above the estimate in the improved site analysis. Regionally, transportation related losses increase by $3.75 billion to reach $5.04 billion in total transportation loss.

Table 207: Direct Building Losses ($ thousands) – Level II SW

	Capital Losses					Income Losses				
	Structural Damage	Non-Structural Damage	Contents Damage	Inventory Loss	Loss Ratio	Relocation Loss	Capital Related Loss	Wages Loss	Rental Income Loss	Total Loss
Alabama	$3,946	$22,809	$11,863	$520	0.12	$56	$676	$1,073	$989	**$41,932**
Arkansas	$1,667,172	$5,841,246	$1,888,170	$76,277	12.2	$37,610	$212,435	$290,888	$477,685	**$10,491,483**
Illinois	$105,430	$399,150	$137,236	$2,929	1.78	$2,102	$9,399	$12,009	$26,186	**$694,441**
Indiana	$16,754	$66,090	$27,416	$1,534	0.43	$276	$1,202	$1,611	$3,795	**$118,678**
Kentucky	$364,983	$1,162,988	$378,779	$11,309	4.33	$7,955	$69,307	$99,156	$101,406	**$2,195,883**
Mississippi	$322,230	$1,044,604	$383,115	$20,051	3.87	$7,215	$90,918	$130,734	$104,492	**$2,103,359**
Missouri	$620,465	$2,125,796	$721,173	$27,839	5.28	$13,278	$70,960	$102,694	$166,567	**$3,848,772**
Tennessee	$2,298,756	$7,784,561	$2,746,724	$96,806	7.81	$51,147	$510,327	$690,919	$709,962	**$14,889,202**
TOTAL	***$5,399,736***	***$18,447,244***	***$6,294,476***	***$237,265***		***$119,639***	***$965,224***	***$1,329,084***	***$1,591,082***	***$34,383,750***

Table 208: Direct Transportation Losses ($ thousands) – Level II SW

	Transportation							
	Highway	Railway	Light Rail	Bus Facility	Ports	Ferries	Airports	Total
Alabama	$2,355	$736	$0	$64	$2,820	$0	$3,365	**$9,340**
Arkansas	$1,590,988	$112,397	$0	$1,148	$36,971	$0	$134,891	**$1,876,395**
Illinois	$171,264	$13,855	$0	$1,019	$17,842	$2,420	$32,119	**$238,519**
Indiana	$2,636	$3,126	$0	$37	$5,754	$0	$8,662	**$20,215**
Kentucky	$355,964	$27,155	$0	$609	$43,333	$1,068	$22,362	**$450,491**
Mississippi	$119,202	$6,506	$0	$566	$5,241	$0	$35,802	**$167,317**
Missouri	$923,199	$79,863	$0	$4,201	$53,672	$1,123	$83,236	**$1,145,294**
Tennessee	$903,136	$87,241	$3	$2,889	$62,607	$959	$80,237	**$1,137,072**
TOTAL	***$4,068,744***	***$330,879***	***$3***	***$10,533***	***$228,240***	***$5,570***	***$400,674***	***$5,044,643***

Utility losses by state are displayed in Table 209. With buildings and transportation losses increasing drastically it only follows that utility losses increase in the same fashion. An additional $1 billion in losses occurs in Arkansas, though Missouri and Tennessee also add several hundred million each. Overall, utility losses increase by $1.1 billion for a total regional loss of $2.5 billion.

All state and major system losses are compiled in Table 210. Alabama shows a decrease in regional losses, though this amount is so small that the change is negligible on the regional level. Most of the additional losses incurred across the study region are attributed to Arkansas and Tennessee, which comprise 68% of all additional losses. An additional $21 billion are added to the direct loss estimate for an earthquake at the southwest fault extension. Total regional losses are now estimated at approximately $50.5 billion.

Table 209: Direct Utility Losses ($ thousands) – Level II SW

	Utility Systems						
	Potable Water	Waste Water	Oil Systems	Natural Gas	Electric Power	Communication	Total
Alabama	$1,750	$16,831	$1	$478	$9,417	$38	**$28,515**
Arkansas	$420,561	$2,931,109	$84	$288,277	$414,578	$1,888	**$4,056,497**
Illinois	$61,736	$515,297	$8	$11,081	$72,231	$332	**$660,685**
Indiana	$5,000	$20,477	$9	$394	$8,083	$34	**$33,997**
Kentucky	$74,331	$443,710	$1	$19,164	$67,567	$507	**$605,280**
Mississippi	$28,106	$392,672	$0	$21,483	$59,774	$386	**$502,421**
Missouri	$392,771	$1,929,849	$6	$150,208	$355,917	$1,193	**$2,829,944**
Tennessee	$200,617	$1,884,104	$250	$80,381	$149,870	$2,179	**$2,317,401**
TOTAL	***$1,184,872***	***$8,134,049***	***$359***	***$571,466***	***$1,137,437***	***$6,557***	**$11,034,740**

Table 210: Total Direct Losses – Level II SW

Total Loss

	Liquefaction	Diff. from Improved	% Difference
Alabama	0.08	0.00	-0.01%
Arkansas	16.42	7.41	20.96%
Illinois	15.94	15.09	42.70%
Indiana	0.17	0.07	0.21%
Kentucky	3.25	1.56	4.41%
Mississippi	2.77	0.73	2.05%
Missouri	7.82	3.65	10.32%
Tennessee	18.34	6.84	19.36%
Total	**$64.8**	**$35.4**	

Total Loss

	Liquefaction	Diff. from Improved	% Difference
Buildings	$34.38	$14.73	70.09%
Transporation	$5.04	$3.76	17.88%
Utilities	$11.03	$2.53	12.03%
Total	**$50.5**	**$21.0**	

Indirect economic losses change as well, with employment needs decreasing by approximately 50%. This proportion holds for the first two years of regional recovery, with the first year requiring only 3 million jobs. First year indirect economic impact shows gains of nearly $5 billion, which is in direct contrast to the improved Level I analysis. Table 211 shows the remaining indirect losses and employment requirements for the first fifteen years after the scenario earthquake.

Table 211: Indirect Economic Losses ($ millions) – Level II SW

	Loss	Total	%
First Year	Employment Impact	2,985,980	-100.27
	Income Impact	-5,648	-3.98
Second Year	Employment Impact	1,384,602	46.49
	Income Impact	10,641	7.51
Third Year	Employment Impact	171,238	5.75
	Income Impact	8,799	6.21
Fourth Year	Employment Impact	9,644	0.32
	Income Impact	-563	-0.40
Fifth Year	Employment Impact	544	0.02
	Income Impact	-1,090	-0.77
Years 6 to 15	Employment Impact	27	0.00
	Income Impact	-1,120	-0.79

6.3.4 Pipeline Networks

The Homeland Security Infrastructure Program (HSIP) GOLD data set provides information on various types of buildings, transportation and utility networks and systems. Natural gas and oil pipeline data is extracted from those numerous data sets and added to the HAZUS-MH utility distribution network inventory. Natural gas lines carry natural gas and propane, normal butane, iso-butane and natural gasoline (LPG/NGL), while oil pipelines carry crude oil, refined oil or petrochemicals. These distribution networks only include the types of pipelines shown in Table 212. In some cases a diameter is not specified for pipeline segments, in which case the diameters appearing in the pipeline table are assigned to those particular segments. The diameters are averages taken from large sets of pipeline data and are only used to determine the type of repair rate equation that is applied to a particular pipeline. These pipeline types apply to both natural gas and oil classifications.

Table 212: Pipeline Types in HSIP

Pipeline Type	Diameter (in.)
Transmission/Trunk Line	17
Gathering System Main Line	8
Gathering System Field Line	6
Local Distribution Line	7

When pipeline network data is added to HAZUS-MH all inventory assumptions used to determine pipeline damage for gas and oil lines are negated. This means the baseline estimation of local distribution lines (to individual homes) is no longer applicable and all pipeline damage and loss predictions are carried out for the regional pipeline network only, as this is the extent of pipeline information provided in the HSIP GOLD dataset. Regional pipeline networks for natural gas and oil are depicted in Figure 140 for the study region under investigation here. It is evident from the illustration that local distribution networks which provide service to individual homes are not included in the dataset and thus provide a critical point of comparison with basic HAZUS-MH pipeline assumptions which account for these pipeline segments.

The northeast extension event shows damage which reaches a maximum regional value in only one segment of oil pipeline and just a few segments of natural gas lines. As shown in Figure 141 & Figure 142 maximum break rates only reach 0.035 and 0.090 breaks/m for natural gas and oil lines, respectively. These high damage rates are confined to southern Illinois and southeastern Missouri, primarily. Leak and repair rates show similar distributions, though their maximum rate values are substantially larger.

Leak rates for natural gas and oil pipelines reach maximums of 0.139 and 0.037 leaks/m, while repair rate maximums are 0.174 and 0.046 repairs/m, respectively.

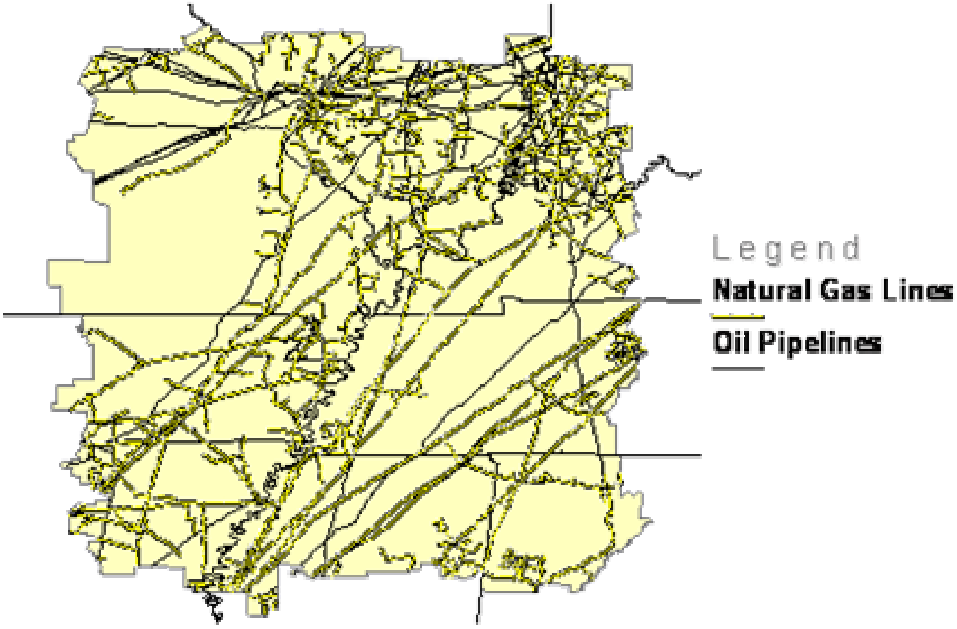


Figure 140: Oil and Natural Gas Pipelines from HSIP

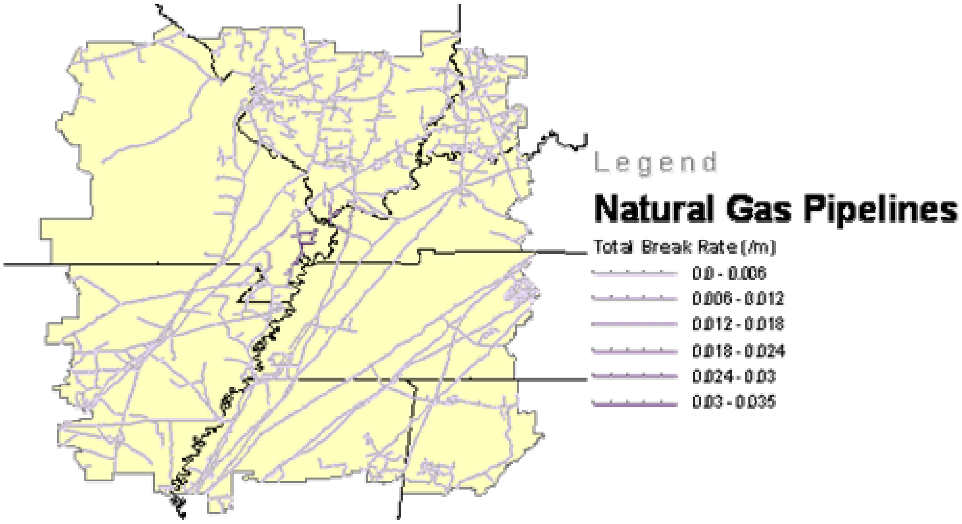


Figure 141: NE Epicenter - Natural Gas Line Break Rate

The central source experiences the majority of its pipeline damage in southeastern Missouri as well as parts of northwestern Tennessee and northeastern Arkansas. Figure 143 & Figure 144 display regional break rates for this scenario earthquake which are meant to be illustrative of all damage and repair rate distributions. Break rates for natural gas and oil peak at 0.035 and 0.0092 breaks/m, respectively. Maximum leak rates for natural gas lines reach 0.139 leaks/km, while oil lines only reach 0.037 leaks/m. Natural gas line maximum repair rates are ten times greater than oil lines at 0.174 repairs/m, versus only 0.046 repairs/m.

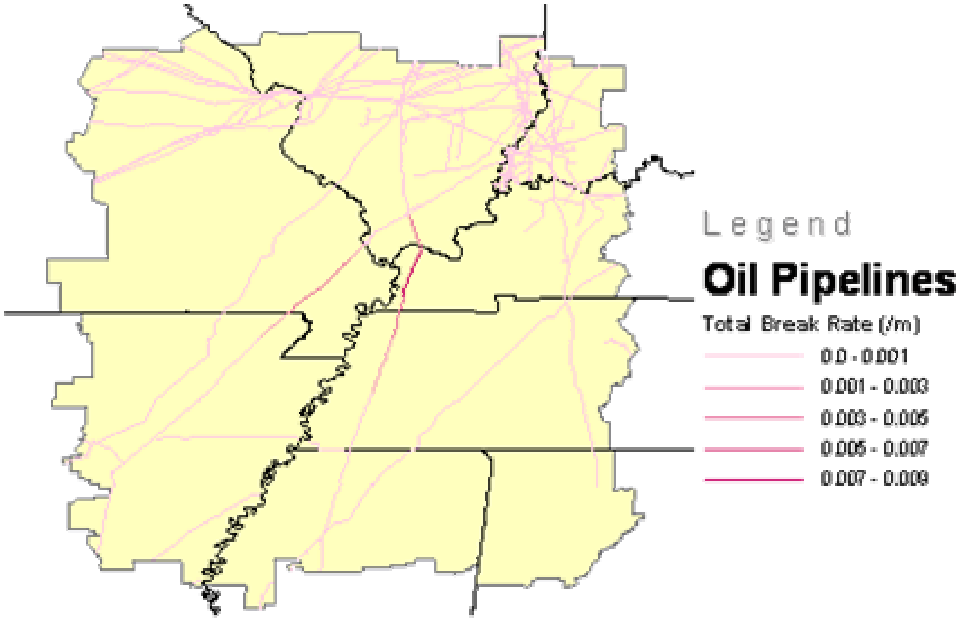


Figure 142: NE Epicenter - Oil Pipeline Break Rate

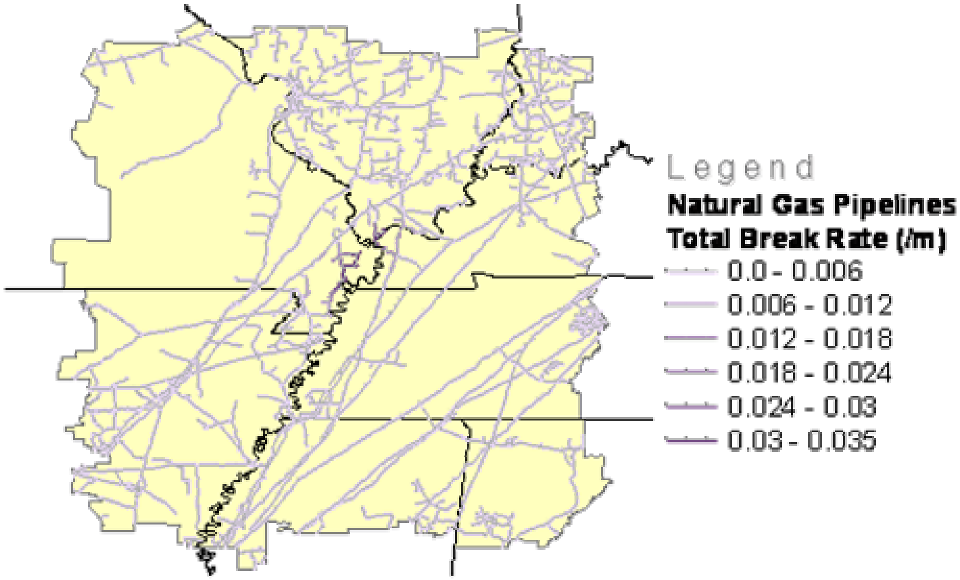


Figure 143: Central Epicenter - Natural Gas Line Break Rate

Pipeline damage for natural gas and oil lines for a scenario earthquake at the southwest extension are illustrated in Figure 145 & Figure 146. Again, while only break rates are shown for these two pipeline distribution networks leak and repair rates show similar distributions and maximum locations though the rates themselves are different. The maximum leak rates for natural gas and oil lines are 0.175 and 0.016 leaks/m while repair rates for these same networks are 0.218 and 0.02 repairs/m, respectively. It is also relevant to note that the southwest source exhibits higher break rates than the previous epicenters for natural gas lines, though the central extension shows the greatest oil break rate by far, at 0.0092 breaks/m.

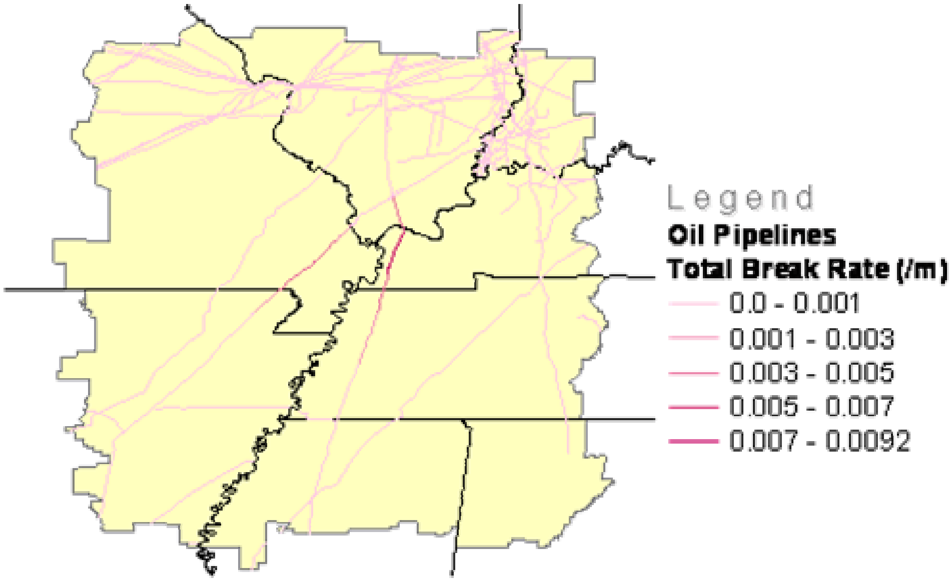


Figure 144: Central Epicenter - Oil Pipeline Break Rate

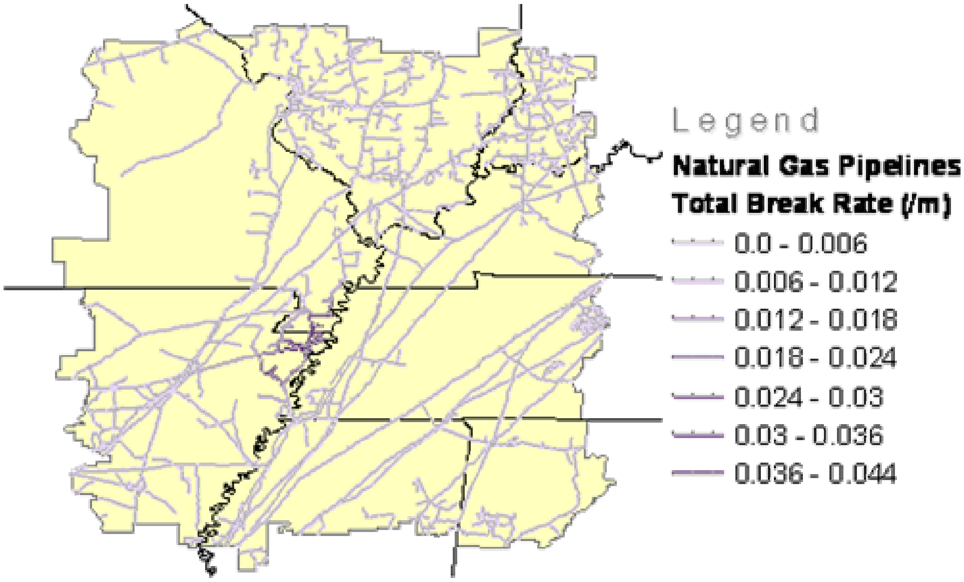


Figure 145: SW Epicenter - Natural Gas Line Break Rate

In order to calculate the number of leaks, breaks and required repairs the pipeline networks must be reprojected onto a flat coordinate system. This displays pipeline lengths in units of meters which are multiplied by the break rates (damage/m) to calculate the number of damage occurrences over the specific length of pipe. Each segment's damage is then totaled to find the number of breaks, leaks and repairs expected across the entire study region. These values appear in Table 213 for each of the three source fault extensions. The 'HAZUS-MH Default' category refers to the default assumptions of natural gas line damage only, and not the default or Level I analysis case. The estimates of break and leaks used for comparison here are taken from the Level II analysis with liquefaction susceptibility data. Every extension shows the greatest estimates of damage belonging to the HAZUS-MH estimates. All extensions show drastic reductions in damage for all fault extensions. The central and northeast extensions show identical oil line damage, while southwest extension damage values are very similar. Since HAZUS-MH provides no internal damage estimate the break and leak values determined here are the only estimates available in this study. Natural gas lines show similar trends to those displayed with oil lines. Natural gas lines damage values, however; are much greater. These values are less than 1% of the HAZUS-MH estimated values for each fault extension.

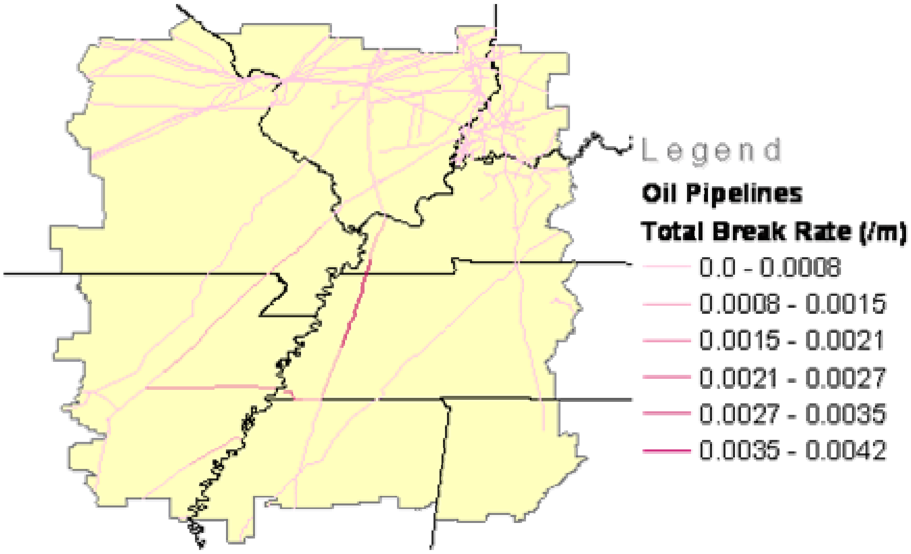


Figure 146: SW Epicenter - Oil Pipeline Break Rate

Table 213: Pipeline Damage with the HSIP Gold Dataset

	Northeast Extension			Central Extension			Southwest Extension		
	No. Leaks	No. Breaks	No. Repairs	No. Leaks	No. Breaks	No. Repairs	No. Leaks	No. Breaks	No. Repairs
Natural Gas Lines									
HAZUS-MH Default	21,339	36,625	57,964	21,582	37,574	59,156	33,430	49,860	83,290
HSIP	102	25	129	102	25	129	158	38	195
Difference	21,237	36,600	57835	21,480	37,549	59027	33,272	49,822	83095
Total (HAZUS+HSIP)	21,339	36,625	57,964	21,582	37,574	59,156	33,430	49,860	83,290
Oil Pipelines									
HSIP	7	2	9	7	2	9	10	2	12

The drastic differences in damage estimations greatly affect system service disruptions to regional customers, which are not calculated by HAZUS-MH for natural gas and oil pipelines. While pipeline functionalities are calculated in the program no break or leak rates are large enough to permit the calculation of non-negligible system downtime. HSIP pipelines exhibit no repair needs with regard to the time needed to fix broken lines, despite number of repairs called for in the previous table (Table 213). Furthermore, pipeline losses are not determined by HAZUS-MH when external pipeline data is provided. Without this information there is no way to compare loss values from the Level II liquefaction analysis with pipeline losses here. It is possible to assign loss values to each break and leak externally, though this information is not known and thus not incorporated. With this in mind, only pipeline damage comparisons are permitted. These damage comparisons show that HAZUS-MH provides much greater estimates of all forms of pipeline damage for natural gas and oil pipelines.

6.3.5 Building Fragilities

HAZUS-MH fragility curves for the general building stock are updated with new fragility curves developed by the MAE Center. These fragility curves apply to each of the 36 specific buildings types (See *HAZUS-MH Technical Manual* for classifications) and all code levels; Pre-Code, Low-Code, Moderate-Code and High-Code. Only the former three code types are employed herein as high-code buildings do not exist in the CEUS. In addition, four damage states are considered with the MAE Center set of building fragilities; at least slight damage, at least moderate damage, at least extensive damage and complete damage. This broad range of curves permits the modification of regional damage to building types, code levels and damage states present in HAZUS-MH.

Building fragility curves are parameterized so that a generic set of curves is derived. These curves are dependent of three parameters; stiffness, strength and ductility, which closely relate to serviceability, damage control and collapse prevention limit states, respectively. A Response Database was employed with pre-determined inelastic structural responses which eliminated cumbersome simulation time since new fragilities could be derived directly. Maximum responses were estimated using the nonlinear static procedure (NSP) with SDOF simplification of multi-degree of freedom structures (Jeong & Elnashai, 2006).

The fragility curves developed by Jeong and Elnashai (2006) are based on spectral acceleration while HAZUS-MH fragilities are based on spectral displacement (FEMA-NIBS, *Technical Manual*, 2006). This prohibits the incorporation of these curves in the program so an external damage analysis is required. The conversion process first requires the determination of Memphis, Tennessee, damage probabilities since the fragilities were originally developed for this geographic area. Each building type requires its own set of probabilities as is shown in Table 214. The spectral displacement value is identified for the Memphis region, which is also the value used to determine the damage states appearing in Table 214. The limit states (LS #1, LS #2, etc.) are adjusted according to:

$$P(LS/e) = \Phi\left(\frac{\ln(e) - \lambda}{\beta}\right)$$

where $P(LS/e)$ = Probability of exceeding a given limit state at a given earthquake intensity;

Φ = Standard normal cumulative distribution function;

e = Spectral acceleration;

λ, β = Modification parameters developed by MAE Center analyses

This procedure is repeated for all structure types and seismic design levels which are then complied into an updated version of Table 214. Results of the original damage states and updated damage states are compared and a ratio calculated (Parameterized Fragility damage value/HAZUS-MH damage value) which converts HAZUS-MH damage values to damage values representative of MAE Center fragilities. Finally, Table 214 is completed with the damage ratios which added to building damage figures from HAZUS-

MH which permits the calculation of MAE Center-based general building stock damage. It is relevant to note that due to the external calculation of damage no economic loss values are determined for MAE Center general building stock damage.

HAZUS-MH employs a Capacity Spectrum Method (CSM) which identifies an intersection point of structural capacity and demand curves. The resulting fragilities incorporate empirical data, though the curves are largely influenced by expert opinion. Some curves are almost entirely dependent on engineering expertise as fragilities for some buildings types are widely studied. The updated fragilities developed in the MAE Center provide a scientific basis for all building type fragilities and thus provide a more accurate representation of building performance.

Table 214: Fragility Curve Development - Memphis

	LS #1	LS #2	LS #3	LS #4
W1-H				
W1-M				
W1-L				
W1-P				
????				
????				
????				

Updating general building stock damage reveals less damage to most specific buildings types at all damage and seismic code levels. All comparisons made here employ general building stock damage from the Level II analysis of the southwest extension event. This means that building damage incorporates ground motion amplified by ground motion and adjusted by permanent ground deformations induced by liquefaction.

Light wood frames are one of the most prominent building types in this CEUS study region and also experience the most significant change in damage. Both low- and moderate-code levels show dramatic increases in the number of buildings appearing in each damage state. Most noticeably, building collapse increase to 94,000 when MAE Center fragilities are used. HAZUS-MH estimates approximately 37,000 moderate-code collapses, which is roughly 35% of MAE Center estimated damage. At least extensive damage shows over 82,000 more occurrences with updated fragilities, while at least moderate experiences roughly 58,000 more instances of each damage category. Table 215 displays these values for moderate- and low-code.

Table 215: Updated Light Wood Frame (W1) Damage

		W1 - Pre Code	W1 - Low Code	W1 - Moderate Code
	Total Building Count	0	2,117,904	488,853
Damage from HAZUS (number of buildings)	**At Least Slight**	No Inventory	101,038	218,076
	At Least Moderate		17,470	86,748
	At Least Extensive		8,007	51,529
	Complete		7,719	48,551
Improved Damage (number of buildings)	**At Least Slight**	No Inventory	106,629	265,593
	At Least Moderate		19,936	142,300
	At Least Extensive		9,981	131,587
	Complete		11,560	138,796

The only other building type to experience any form of increased damage is mobile homes, though only low- and moderate-code buildings realize more damage when fragilities are updated. This is illustrated in Table 216. More extensive damage states show the greatest increases in building damage. At least extensive and complete damage states experience increases of more than 30%. Lesser damage states incur only 2%-15% damage increase. While low- and moderate-code buildings see more damage, pre-code buildings experience less damage when fragilities are updated. Complete damage, for instance, is reduced by half when fragilities are updated. The remainder of the specific building types incurs less damage than HAZUS-MH estimates. Building type W2, commercial and industrial wood construction, sees the greatest change to pre-code buildings, while moderate-code structures only incur 10-20 fewer occurrences of damage at various damage states. Low-code buildings represent a small portion of regional W2 inventory and thus experience little change. Table 217 illustrates these results for all code levels and damage states.

Table 216: Updated Mobile Home (MH) Damage

		MH - Pre Code	MH - Low Code	MH - Moderate Code
	Total Building Count	268,227	169,644	45,373
Damage from HAZUS (number of buildings)	**At Least Slight**	101,154	32,757	36,464
	At Least Moderate	56,468	16,995	31,015
	At Least Extensive	30,257	3,327	19,689
	Complete	11,882	1,429	10,921
Improved Damage (number of buildings)	**At Least Slight**	96,737	33,581	37,380
	At Least Moderate	50,070	16,995	33,122
	At Least Extensive	20,528	3,327	23,001
	Complete	5,476	1,429	15,063

Table 217: Adjusted Commercial & Industrial Wood (W2) Damage

		W2 - Pre Code	W2 - Low Code	W2 - Moderate Code
	Total Building Count	6,801	1,386	1,270
	At Least Slight	1,023	82	783
Damage from HAZUS	**At Least Moderate**	603	26	306
(number of buildings)	**At Least Extensive**	194	6	143
	Complete	97	6	118
	At Least Slight	925	76	766
Improved Damage	**At Least Moderate**	459	26	293
(number of buildings)	**At Least Extensive**	100	6	135
	Complete	39	6	102

All steel building types (S1L, S2L, S3, S4L & S5L) all show relatively the same damage modifications. Updated damage values are illustrates in Table 218- Table 222. At least slight damage decreases between 5% and 20% depending on code level and specific building type. At least moderate damage is reduced by 10%-30%, while at least extensive damage drops by 20%-50%. Complete damage experiences the greatest reductions which are between 45% and 75% of original HAZUS-MH damage estimates.

Table 218: S1L Adjusted Damage

		S1L - Pre Code	S1L - Low Code	S1L - Moderate Code
	Total Building Count	1,536	111	91
	At Least Slight	232	1	64
Damage from HAZUS	**At Least Moderate**	98	0	41
(number of buildings)	**At Least Extensive**	51	0	14
	Complete	18	0	14
	At Least Slight	199	1	62
Improved Damage	**At Least Moderate**	73	0	38
(number of buildings)	**At Least Extensive**	25	0	12
	Complete	7	0	7

Table 219: S2L Adjusted Damage

		S2L - Pre Code	S2L - Low Code	S2L - Moderate Code
	Total Building Count	345	233	187
	At Least Slight	89	6	130
Damage from HAZUS	**At Least Moderate**	77	2	80
(number of buildings)	**At Least Extensive**	55	1	25
	Complete	22	0	16
	At Least Slight	74	5	122
Improved Damage	**At Least Moderate**	56	2	71
(number of buildings)	**At Least Extensive**	25	1	20
	Complete	7	0	11

Table 220: S3 Adjusted Damage

		S3 - Pre Code	S3 - Low Code	S3 - Moderate Code
	Total Building Count	3,147	978	549
Damage from HAZUS (number of buildings)	**At Least Slight**	807	96	490
	At Least Moderate	544	58	401
	At Least Extensive	334	23	161
	Complete	166	5	68
Improved Damage (number of buildings)	**At Least Slight**	754	91	482
	At Least Moderate	477	58	387
	At Least Extensive	236	23	148
	Complete	67	5	56

Table 221: S4L Adjusted Damage

		S4L - Pre Code	S4L - Low Code	S4L - Moderate Code
	Total Building Count	1,441	978	232
Damage from HAZUS (number of buildings)	**At Least Slight**	234	173	169
	At Least Moderate	173	131	110
	At Least Extensive	119	60	36
	Complete	51	26	21
Improved Damage (number of buildings)	**At Least Slight**	196	148	158
	At Least Moderate	128	131	99
	At Least Extensive	59	60	30
	Complete	14	26	15

Table 222: S5L Adjusted Damage

		S5L - Pre Code	S5L - Low Code	S5L - Moderate Code
	Total Building Count	2,113	669	309
Damage from HAZUS (number of buildings)	**At Least Slight**	318	31	275
	At Least Moderate	204	12	234
	At Least Extensive	125	3	130
	Complete	52	1	61
Improved Damage (number of buildings)	**At Least Slight**	284	29	Not Available
	At Least Moderate	161	12	
	At Least Extensive	75	3	
	Complete	19	1	

Concrete and precast structures experience roughly the same reduction in the occurrence of damage for various damage states. At least slight damage reductions occur over a lesser range, only 6%-12% reductions from HAZUS-MH damage estimates. At least moderate damage also shows a tighter range of damage reduction, 15-25%. At least extensive and complete damage realize a much broader range of damage modifications, however. Damage cases are reduced by 20%-50% and 30%-65%, respectively (See Table 223 -Table 227). These reductions depend on code level primarily.

Table 223: C1L Adjusted Damage

		C1L - Pre Code	C1L - Low Code	C1L - Moderate Code
	Total Building Count	409	34	23
Damage from HAZUS (number of buildings)	**At Least Slight**	32	1	20
	At Least Moderate	11	0	16
	At Least Extensive	4	0	8
	Complete	2	0	3
Improved Damage (number of buildings)	**At Least Slight**	28	1	19
	At Least Moderate	8	0	15
	At Least Extensive	2	0	7
	Complete	1	0	2

Table 224: C2L Adjusted Damage

		C2L - Pre Code	C2L - Low Code	C2L - Moderate Code
	Total Building Count	5,644	843	387
Damage from HAZUS (number of buildings)	**At Least Slight**	534	66	311
	At Least Moderate	294	36	258
	At Least Extensive	178	10	154
	Complete	87	2	73
Improved Damage (number of buildings)	**At Least Slight**	470	60	289
	At Least Moderate	228	36	222
	At Least Extensive	104	10	119
	Complete	29	2	46

Table 225: C3L Adjusted Damage

		C3L - Pre Code	C3L - Low Code	C3L - Moderate Code
	Total Building Count	132	0	0
Damage from HAZUS (number of buildings)	**At Least Slight**	9	No Inventory	No Inventory
	At Least Moderate	2		
	At Least Extensive	0		
	Complete	0		
Improved Damage (number of buildings)	**At Least Slight**	9	No Inventory	No Inventory
	At Least Moderate	2		
	At Least Extensive	0		
	Complete	0		

Table 226: PC1 Adjusted Damage

		PC1 - Pre Code	PC1 - Low Code	PC1 - Moderate Code
	Total Building Count	2,658	956	388
Damage from HAZUS (number of buildings)	**At Least Slight**	533	74	265
	At Least Moderate	375	42	165
	At Least Extensive	221	12	67
	Complete	94	2	44
Improved Damage (number of buildings)	**At Least Slight**	490	70	256
	At Least Moderate	325	42	154
	At Least Extensive	163	12	59
	Complete	46	2	37

Code level plays a significant role in the amount of damage determined by MAE Center fragilities. Pre-code buildings show much greater reductions in damage than low-code, and especially moderate-code buildings. Numerous specific buildings types see less than 15% reductions for all damage states at the moderate-code level, while pre-code building only experience these small reductions at mild damage states. Extensive and complete damage states decrease by more than 40% frequently. This is particularly evident with PC1 buildings (See Table 226) and reinforced masonry buildings (See Table 228 & Table 229). In fact, damage modification to both types of reinforced masonry structures, RM1L and RM2L, exhibit the same trends as though previously discussed for precast structures. Unreinforced masonry damage, illustrated in Table 230, realizes damage reductions of 10%-20% at lesser damage states (at leas slight and moderate) while reductions of 20%-40% occur for at least extensive and complete damage levels.

Table 227: PC2L Adjusted Damage

		PC2L - Pre Code	PC2L - Low Code	PC2L - Moderate Code
	Total Building Count	203	10	13
Damage from HAZUS (number of buildings)	**At Least Slight**	14	0	9
	At Least Moderate	8	0	6
	At Least Extensive	3	0	2
	Complete	1	0	2
Improved Damage (number of buildings)	**At Least Slight**	12	0	8
	At Least Moderate	6	0	5
	At Least Extensive	2	0	2
	Complete	0	0	1

Table 228: RM1L Adjusted Damage

		RM1L - Pre Code	RM1L - Low Code	RM1L - Moderate Code
	Total Building Count	2,425	139	516
Damage from HAZUS (number of buildings)	**At Least Slight**	211	1	267
	At Least Moderate	145	0	164
	At Least Extensive	70	0	92
	Complete	17	0	66
Improved Damage (number of buildings)	**At Least Slight**	189	1	265
	At Least Moderate	122	0	162
	At Least Extensive	50	0	90
	Complete	8	0	64

Table 229: RM2L Adjusted Damage

		RM2L - Pre Code	RM2L - Low Code	RM2L - Moderate Code
	Total Building Count	170	56	0
Damage from HAZUS (number of buildings)	**At Least Slight**	4	0	No Inventory
	At Least Moderate	1	0	
	At Least Extensive	0	0	
	Complete	0	0	
Improved Damage (number of buildings)	**At Least Slight**	3	0	No Inventory
	At Least Moderate	1	0	
	At Least Extensive	0	0	
	Complete	0	0	

Table 230: URML Adjusted Damage

		URML - Pre Code	URML - Low Code	URML - Moderate Code
	Total Building Count	287,023	168,716	59,642
Damage from HAZUS (number of buildings)	**At Least Slight**	55,784	15,383	49,494
	At Least Moderate	32,147	8,334	38,103
	At Least Extensive	17,934	2,072	20,535
	Complete	8,712	888	12,698
Improved Damage (number of buildings)	**At Least Slight**	53,285	14,941	Not Available
	At Least Moderate	29,013	8,334	
	At Least Extensive	14,560	2,072	
	Complete	6,184	888	

The updated damage estimates do not include all 36 specific buildings types since only the 16 discussed in this subsection are present in the CEUS study region, though fragilities exist for the unused buildings types. Overall, most building types show fewer cases of damage at all damage levels with the exceptions of light wood frames and mobile homes at low- and moderate-code levels. While these are only two of the 16 buildings types investigated here it is relevant to note that these two specific building types represent nearly 85% of regional buildings.

7 Analysis Level and Regional Comparisons

7.1 Hazard/Site Affects

The impact of site affects and liquefaction susceptibilities are well documented in previous sections, though a short review of these affects is still warranted here. The application of regional site data affects all ground shaking parameters supplied to HAZUS-MH as user-input hazard maps. Each epicenter/fault extension exhibited increased maximum PGA and short-period spectral acceleration values. These changes are anywhere from 5%-50% of the default, site class 'D' values. Long-period spectral acceleration and PGV parameters show increases of 40%-60% for maximum regional values. Also, census tracts within the Mississippi Embayment region of the study area show increased seismic response values, though these are considered mid-range shaking in comparison to maximum values at the epicenters. When the three source scenarios are compared the greatest shaking values, as determined by maximum shaking at the source, occurs at various fault extensions where shaking modified by site data reaches the following; PGA – 1.38*g* (northeast), PGV – 52.1 in./sec. (southwest), S_a 0.3 sec. – 2.1*g* (northeast) and S_a 1.0 sec.- 1.43*g* (central).

Liquefaction susceptibility does not directly affect ground shaking in HAZUS-MH, though the probabilities of liquefaction calculated based on these susceptibility values do take PGA into account. The addition of this information does permit the determination of permanent ground deformations of vertical settlement and lateral spreading. While each extension appears to exhibit roughly the same settlement patterns and values, lateral spreading appears to affect the central and southwest extensions more than the northeast. This is due to the positioning of the two former source faults in the Mississippi Embayment which represents the region's most liquefiable soils.

7.2 Determination of Worst-Case Scenario

7.2.1 Level 1 Comparison of Three Epicenters

The results of each individual Level I analysis are well catalogued in previous sections though it is necessary to use this information to determine a worst-case scenario earthquake for the study region under investigation. Based on the breadth and depth of the result parameters provided by HAZUS-MH there are numerous methods by which to determine what scenario earthquake produces the most damage in a given region. Prior to the examination of regional economic losses it is relevant to consider the damage, loss of shelter and life that define regional earthquakes.

Damage to the general building stock for each epicenter is detailed in Table 231. It is evident from this data that the southwest epicenter shows the greatest number of collapsed buildings, be they light wood frames, unreinforced masonry or mobile homes. Extensive damage cases for URMs is greatest with a southwest event while mobile homes is greatest with the southwest source.

Table 231: General Building Stock Damage - Level I

	Light Wood Frame				
	None	**Slight**	**Moderate**	**Extensive**	**Complete**
Northeast	2,624,381	106,604	21,386	1,944	142
Central	2,624,630	114,728	14,203	904	57
Southwest	2,466,122	227,216	58,421	2,573	132
	Unreinforced Masonry				
Northeast	414,627	68,748	27,790	9,684	4,579
Central	439,989	54,788	22,094	6,399	2,146
Southwest	445,227	31,324	26,780	16,340	5,734
	Mobile Home				
Northeast	297,276	77,582	83,744	22,428	3,564
Central	296,882	88,580	81,186	16,234	1,699
Southwest	333,527	62,041	68,252	18,009	2,824

Damage to essential facilities is another category by which worst-case scenario may be determined. The number of essential facilities reaching the at least moderate damage state for each epicenter is shown in Table 232. While the northeast exhibits the most damage to hospitals and fire stations the southwest experiences the greatest damage to school and police stations. The central epicenter shows only moderate damage in comparison to the other two epicenters.

Table 232: Essential Facilities Damage - Level I

	Epicenters		
E.F. Type	**Northeast**	**Central**	**Southwest**
Hospitals	39	28	33
Schools	287	220	461
Police Stations	92	103	108
Fire Stations	122	101	109

Table 233: Transportation Damage - Level I

	Epicenters		
Transportation Type	**Northeast**	**Central**	**Southwest**
Highway Bridges	350	371	379
Railway Facilities	12	20	42
Port Facilities	22	17	38
Airport Facilities	5	6	6

Table 234: Utility Facility Damage - Level I

	Epicenter		
Facility Type	**Northeast**	**Central**	**Southwest**
Potable Water	8	7	1
Waste Water	47	22	31
Natural Gas	2	0	0
Oil	0	0	8
Electric Power	4	2	5
Communication	25	11	21

The most prominent transportation facilities are displayed in Table 233 with their corresponding number of components realizing at least moderate damage. The southwest epicenter shows the greatest level of damage in every category. Railway and port facilities damage for the southwest epicenter is twice as much as the central epicenter.

Utility systems damage does not present a clear worst-case, which is consistent with essential facilities and general building stock damage. Table 234 presents the quantity of each utility facility type reaching at least moderate damage. While the northeast epicenter generates the greatest damage to potable water, waste water and communication facilities, oil facilities are much more likely to incur damage when the southwest scenario is applied. Again, the central epicenter event causes no facility type to reach its highest damage count.

Several other comparison parameters include debris generation, shelter requirements and casualties. The greatest amount of debris, seven million tons, is created with the southwest scenario event. The central and northeast events only produce three and five million tons, respectively. Shelter requirements for each fault epicenter event are illustrated in Table 235. The southwest creates the greatest housing losses and temporary shelter requirements by far as this event requires nearly twice as many shelter needs as the other two cases.

Table 235: Housing Requirements - Level I

	Epicenter		
	Northeast	Central	Southwest
Displaced Households	9,924	5,191	18,837
Temporary Housing	2,758	1,554	5,849

Table 236: Casualties - Level I

	Epicenter		
Time of Day	Northeast	Central	Southwest
2:00 AM	2,288	3,963	8,659
2:00 PM	2,614	4,184	13,616
5:00 PM	2,585	3,953	11,683

Yet another critical factor to consider is the extent of regional casualties, or injuries and fatalities. Table 236 details the total number of casualties at all severity levels for the three epicenter events. The southwest epicenter generates the most casualties by over 4,000 at any of the three times of day considered, though the 2 PM interval is undoubtedly the most costly. The northeast and central epicenters are largely unaffected by time of day, while is the northeast epicenter produces the least casualties.

While damage to various inventory components show conflicting results by which to determine the worst-case scenario, direct economic losses show a clear worst-case. Table 237 illustrates the direct economic losses for the major inventory categories as well as total regional loss. While utility losses are greatest with the northeast event building and transportation losses incur far greater losses in the southwest than their counterparts.

As a result, the southwest epicenter is determined to be the worst-case scenario based on total direct economic loss at $15.6 billion. This is 25% more than the northeast epicenter event and 78% greater than the central epicenter event.

Table 237: Direct Economic Losses - Level I

	Epicenters		
Direct Loss Cetegory	**Northeast**	**Central**	**Southwest**
Buildings	$8.51	$5.79	$12.94
Transportation	$0.49	$0.46	$0.58
Utility	$3.48	$2.49	$2.03
Total	***$12.5***	***$8.7***	***$15.6***

7.2.2 Improved Level I Comparison of Three Extensions

As was documented in previous sections, ground motion modified with site affects increase overall damage to the general building stock. Table 238 is used to compare these updated damage counts. Adjustment of the ground motion generates the greatest number of collapses with the southwest epicenter event for URMs and mobile homes. The northeast extension still reports the most light wood frame collapses, however. Extensive damage to mobile homes and URMs is also greatest with the southwest fault. The remaining damage categories show conflicting circumstances generating the largest amount of damage.

Table 238: General Building Stock Damage - Improved Level I

	Light Wood Frame				
	None	**Slight**	**Moderate**	**Extensive**	**Complete**
Northeast	2,536,590	168,305	43,263	6,021	442
Central	2,493,495	204,074	51,449	5,242	372
Southwest	2,417,549	273,037	59,725	4,060	264
	Unreinforced Masonry				
Northeast	422,589	55,655	27,112	10,700	9,446
Central	421,742	46,399	32,180	14,930	10,329
Southwest	405,427	46,332	40,100	19,998	13,754
	Mobile Home				
Northeast	326,463	79,162	49,863	19,455	9,637
Central	326,135	73,127	50,729	24,420	10,129
Southwest	315,459	70,022	53,504	31,746	13,839

Table 239: Essential Facilities Damage - Improved Level I

	Epicenters		
E.F. Type	**Northeast**	**Central**	**Southwest**
Hospitals	22	30	42
Schools	460	633	884
Police Stations	177	221	276
Fire Stations	218	253	305

The improved analysis does not present a clear worst-case with regard to essential facilities damage. At least moderate damage to each facility type is greatest for the southwest event. Table 239 shows that the southwest extension generates the significantly more damage than the other two sources. Nearly twice as many hospitals and schools are damaged from a southwest extension event than a northeast event.

Highway bridges are most affected by an earthquake at the southwest extension which damages nearly 1,200 bridges. This is nearly 25% more than the next largest damage estimate. Railway and port facilities, however; experience their greatest amounts of damage from an event at the northeast extension. Airports also experience their worst-case damage from a southwest source event. Table 240 displays these values as well we those quantities of at least moderate damage for all three extensions.

Table 240: Transportation Facilities Damage - Improved Level I

	Epicenters		
Transportation Type	**Northeast**	**Central**	**Southwest**
Highway Bridges	831	934	1179
Railway Facilities	46	29	36
Port Facilities	114	46	53
Airport Facilities	31	34	48

Table 241: Utility Facilities Damage - Improved Level I

	Epicenter		
Facility Type	**Northeast**	**Central**	**Southwest**
Potable Water	36	23	19
Waste Water	162	163	180
Natural Gas	12	7	6
Oil	1	1	12
Electric Power	16	15	17
Communication	98	100	111

Utility facilities also show varying damage levels across the three extensions. Waste water and oil facilities incur the most damage from the southwest thrust event, while natural gas facilities show their greatest damage when an earthquake strikes in the northeast. Table 241 shows these trends as well as the various extensions that report extreme damage quantities for communication, electric and potable water facilities. With extreme damage cases varying so much between epicenters it is difficult to define a worst-case from these damage results either.

The debris model indicates the largest generation case is the southwest fault with 12 million tons of debris. The northeast and central events produce significantly less as seven and nine million tons, respectively. Further, damage estimates for shelter requirements resulting from this improved analysis are delineated in Table 242. Both the northeast and central fault thrust events displace significantly fewer households than the southwest event does. The same follows for temporary housing requirements, as the southwest fault extension experiences the greatest loss estimates as with previous estimates. Finally, casualty estimates are highest with the southwest scenario results. Table 243 shows that over 21,000 casualties occur at the worst-case time of day in the southwest. The northeast and central extensions generate roughly 4,000-8,000 fewer casualties.

Table 242: Shelter Requirements - Improved Level I

	Epicenter		
	Northeast	Central	Southwest
Displaced Households	18,507	21,382	27,513
Temporary Housing	5,313	6,242	8,095

Table 243: Casualties - Improved Level I

	Epicenter		
Time of Day	Northeast	Central	Southwest
2:00 AM	11,083	12,524	15,763
2:00 PM	12,962	15,467	21,026
5:00 PM	12,042	14,201	18,992

Table 244: Total Direct Economic Losses - Improved Level I

	Epicenters		
Direct Loss Cetegory	**Northeast**	**Central**	**Southwest**
Buildings	$13.98	$15.30	$19.66
Transportation	$1.16	$1.05	$1.29
Utility	$9.42	$7.57	$8.51
Total	***$24.6***	***$23.9***	***$29.5***

As with the Level I analysis the worst-case is determined based on total, direct economic loss. Table 244 illustrates losses incurred by each major inventory system due to a scenario earthquake at each epicenter. Utility losses are highest in the northeast scenario at $9.4 billion. Both building and transportation losses report their most extreme loss values with the southwest event. Roughly $19.7 and $1.29 billion are estimated for these two major inventory categories, which contribute to the total loss of $29.5 billion at the southwest epicenter. Again, the southwest event is worst-case as it shows 20% more loss than the northeast event and 23% more loss than the central event.

7.2.3 Level II Comparison of Three Extensions

The addition of liquefaction susceptibilities greatly increases the number of damaged buildings resulting from an earthquake at each extension. It is clear from the quantities shown in Table 245 that light wood frames suffer the most damage with an earthquake in the northeast. The same is true of extensive damage, though moderate and slight are worst with a northeast event. Complete damage to unreinforced masonry structures in most severe with a southwest event, which is the case for extensive and moderate damage as well. Mobile homes also show extreme cases of damage at the southwest extension for the most severe damage states. Unfortunately, no clear worst-case can be determined from this data, unless the critical damage category is collapse.

Table 245: General Building Stock Damage - Level II

	None	Slight	Moderate	Extensive	Complete
	Light Wood Frame				
Northeast	2,491,106	157,017	37,923	5,355	63,242
Central	2,459,409	188,644	46,548	5,071	54,957
Southwest	2,385,421	251,064	52,004	3,520	62,624
	Unreinforced Masonry				
Northeast	416,209	53,784	25,231	9,450	20,823
Central	419,877	44,747	29,650	13,320	17,999
Southwest	404,381	44,657	36,918	17,943	21,673
	Mobile Home				
Northeast	323,556	77,100	47,078	17,350	19,490
Central	324,749	71,532	47,513	21,776	19,014
Southwest	314,610	68,862	50,159	28,271	22,667

Essential facilities show extreme quantities of at least moderate damage occurring at the southwest extension. As was discussed in the Level II Analysis section, at least moderate damage counts do not change between the improved Level I analysis and Level II analysis. Table 246 quantifies at least moderate damage to all essential facility types at each of the three extensions.

Table 246: Essential Facilities Damage - Level II

	Epicenters		
E.F. Type	**Northeast**	**Central**	**Southwest**
Hospitals	22	30	42
Schools	460	633	885
Police Stations	177	221	276
Fire Stations	218	253	305

Table 247: Transportation Damage - Level II

	Epicenters		
Transportation Type	**Northeast**	**Central**	**Southwest**
Highway Bridges	1511	1754	1987
Railway Facilities	55	46	85
Port Facilities	138	83	109
Airport Facilities	43	47	64

Table 248: Utility Facilities Damage - Level II

	Epicenter		
Facility Type	**Northeast**	**Central**	**Southwest**
Potable Water	36	23	19
Waste Water	162	163	180
Natural Gas	12	7	6
Oil	1	1	12
Electric Power	16	15	17
Communication	98	100	111

Port facilities are the only types of transportation structure that does not see its greatest damage count with an event at the southwest epicenter. With 85 railway facilities, 1,987 highway bridges and 64 airport facilities seeing at least moderate damage, the southwest event does indeed realize the most damage in these categories. As shown in Table 247 roughly 15% more bridges are damaged due to an event at the southwest extension than the remaining two sources locations.

The addition of liquefaction susceptibilities does not clarify a worst-case situation with regard to utility systems damage. Table 248 illustrates the distribution utility facilities damage by epicenter. Natural gas and potable water are most susceptible to damage from seismic activity at the northeast extension as 12 and 36, respectively, realize at least moderate damage. Electric power, waste water and communications facilities are damaged most severely by a southwest fault rupture earthquake while oil facilities damage remains dependent on southwest ground motions.

As with previous analysis levels debris generation is greatest with the southwest event. Approximately 18 million tons of debris is created, while the northeast and central epicenters follow with 16 million and 15 million tons, respectively. Shelter requirements are also greatest with the northeast extension event. Over 118,000 households are displaced which is nearly 4,000 more than the southwest event and 19,000 more than the central. Temporary housing needs follow suit as they are at least slightly more than the remaining extensions (See Table 249). Midday casualty estimates from the southwest fault show the largest number of casualties, when all severity levels are considered. Table 250 illustrates the anticipated number of casualties at various times of day, the most critical case at the southwest event is approximately 1,000 casualties more than the next most critical scenario.

Table 249: Shelter Requirements - Level II

	Epicenter		
	Northeast	**Central**	**Southwest**
Displaced Households	118,743	99,544	114,700
Temporary Housing	34,181	28,765	33,374

Table 250: Casualties - Level II

	Epicenter		
Time of Day	**Northeast**	**Central**	**Southwest**
2:00 AM	35,487	31,076	36,350
2:00 PM	31,915	28,688	35,334
5:00 PM	31,920	29,196	35,295

Finally, Level II regional losses for each source fault are considered. Table 251 displays the losses incurred by each major inventory group at each epicenter. Building losses in the southwest are $1.5 billion greater than any other, while utility losses of $11.55 billion occur at the northeast extension and transportation losses of $5.04 billion at the southwest fault segment. The difference in building losses is enough make a southwest epicenter earthquake the worst-case scenario considered in this research. At $50.5 billion in total regional loss the southwest event is nearly $6 billion greater than the next most critical case.

Table 251: Total Direct Economic Losses - Level II

	Epicenters		
Direct Loss Cetegory	**Northeast**	**Central**	**Southwest**
Buildings	$32.90	$28.68	$34.38
Transportation	$4.44	$4.39	$5.04
Utility	$11.55	$9.80	$11.03
Total	***$48.9***	***$42.9***	***$50.5***

7.3 Comparison of Levels I and II

The first analysis case investigated in this research is a baseline, Level I analysis with HAZUS-MH default hazard and inventory assumptions only. The most improved level of analysis carried out in the research is a Level II analysis which makes use of improved site information and liquefaction susceptibility across nearly the entire region. Utility distribution systems are also updated with regional natural gas and oil distribution lines contained in the HSIP GOLD dataset. With all these improvements to the seismic loss model complete it is critical to determine the affects of these improvements.

Of the three fault segments considered both the Level I and Level II analyses show that the southwest event produces the greatest direct economic loss. Changes to regional shaking values have been documented in previous sections, though it is relevant to note again that maximum shaking values at the southwest extension increase for PGV and long-period spectral values while PGA and short-period spectral values do not change as much when the model is improved. Table 252 displays regional damage and loss values for the baseline and improved cases. Building damage is quantified by the number of collapses experienced by the three primary building types. Improving the regional earthquake loss model generates 440 times more cases of complete damage to light wood frames. The revised number of collapses shown by this building type in the Level II analysis renders the baseline estimate virtually negligible as it grossly underestimates the damage incurred by light wood frames. Unreinforced masonry buildings and mobile homes show much less of a difference. While these buildings still show 16,000 and 19,100 more collapses, this pales in comparison to the 63,100 more seen by light wood frames. This dramatic increase in damage can be attributed almost entirely to the addition of regional liquefaction susceptibility information.

Table 252: Level I and Level II Comparison

	Level I	**Level II**
Light Wood Fram Collapses	142	63,242
URML collapses	5,734	21,673
Mobile Home Collapses	3,564	22,667
At Least Moderate Damage:		
Essential Facilities	66	1,508
Highway Bridges	379	1,987
Utility Facilities	86	345
Debris (millions of tons)	7	18
Displaced househlds	18,837	118,743
Temporary housing	5,848	34,181
Casualties	13,616	36,350
Building Loss	$12.94	$34.38
Transportation Loss	$0.58	$5.04
Utility Loss	$2.03	$11.03
Total Direct Economic Loss	**$15.6**	**$50.5**

Damage to key regional facilities, including essential, transportation and utility facilities, increase though by a much lesser margin than the general building stock. Over 1,450 more essential facilities incur at least moderate damage over the course of all model improvements. This increase equates to roughly 22 times more essential facilities experiencing damage. Highway bridge damage is multiplied by nearly five times with the addition of site affects and liquefaction susceptibility. Though not shown here, damage to highway segments, rail segments and airport runways is determined in the most improved analysis. These results can be referenced in the Level II Analysis section. Furthermore, at least moderate damage cases for all utility facilities nearly double as the model is improved, as well.

Modified ground shaking in conjunction with liquefaction-induced settlement and spreading greatly increase damage and the amount of debris generated by regional damage. The default analysis creates seven million tons of debris while the Level II generates more than twice that, or 18 million tons of debris. More damage translates to fewer inhabitable homes, which is reflected in the substantial increase in housing requirements in the Level II analysis. Both displaced household and temporary housing estimates increase by roughly six times from the baseline, default case.

Finally, regional losses show dramatic increases with seismic model improvements. Both transportation and utility losses increase dramatically as each estimate shows additional losses of $4.5 billion and $9 billion, respectively. These major changes are attributed to the inclusion of road and railway losses in the transportation estimate and the addition of improved pipeline losses to the utility systems loss estimate. All of these adjustments are the result of liquefaction susceptibility values which permit the determination of permanent ground deformations that are required to ascertain the damage of paved surface and underground pipelines. Building damage more than doubles between Level I and Level II analyses. This is attributed to intensified ground shaking and permanent ground deformations added to various improved models. Total direct economic loss shows an increase of nearly $34.5 billion. The Level I worst-case scenario shows total losses of $15.6 billion, which increases to nearly $50.5 billion once all seismic risks are considered. This translates to a 225% loss increase from the Level I, baseline model.

The Level II model is considered to be the most regionally accurate model, with updated soil information and regional inventory. All analyses undertaken herein show that each regionally-specific data addition increases the overall loss estimate. This may be contradicted by the addition of HSIP regional utility distribution lines, which actually generate less damage than the baseline HAZUS-MH assumptions for utility networks. For every earthquake scenario, not just the worst-case southwest epicenter, fewer breaks and leaks are anticipated with the HSIP data. Without damage estimations for local distribution networks only major utility lines are assessed damage. This is the case with HSIP utilities, as no pipeline data is available for local lines. If a more conservative estimate of pipeline damage and resulting utility loss is desired then it may be a better choice to use the HAZUS-MH pipeline assumptions even if the damage and loss estimates are higher than actual distribution networks might predict.

Fragilities for the general building stock is updated with MAE Center developed fragilities for all 36 specific building types, four seismic code levels and various damage states, though only four damage states are considered in this research. For most building types, steel, precast concrete, reinforced concrete reinforced masonry and unreinforced masonry, the frequency of build damage decreases for all damage states. Low damage levels such as at least slight and at least moderate show the smallest decreases, while extensive and complete damage reductions are much greater. All code levels show and damage states for these building types show overestimations of damage in HAZUS-MH.

Light wood frame construction and some categories of mobile homes report increased damage. Light wood frames, or W1 structures, show loss increases for all damage states and code levels between 50% and 75% than HAZUS-MH estimates for the same hazard scenario. Mobile homes only experience damage increases with low- and moderate-code buildings, while pre-code structures show reduced damage with updated fragilities. Mobile home damage increases are most prominent at the more severe damage levels as extensive and complete damage occurrences increase by over 30%.

7.4 Comparison with FEMA Baseline Study

As was mentioned earlier a series of baseline studies was completed by FEMA for a series of earthquakes, one on each epicenter of the New Madrid Fault. Each scenario employed shake maps for PGA, PGV, short-period and long-period spectral accelerations. The maps were developed according to the line-source fault rupture methodology discussed in the Project Overview section. Shake maps for PGA and S_a 0.3 Sec. were employed in the improved Level I and Level II analyses conducted in this study. While the northeast extension is not the worst-case scenario determined by FEMA or by this research this event still serves as an appropriate comparison scenario when referenced against Level II northeast analysis completed in this research.

Various result parameters are extracted from FEMA northeast as well as this study region's northeast epicenter for comparison. Table 253 quantifies several key damage and loss variables from the FEMA study and this study. The collapse rates of the three general building types detailed in this comparison show that FEMA-predicted collapse values are roughly twice as much as though shown in results of this study. The transportation system presents a lesser difference margin as the FEMA study shows only 155 more highway bridges are damaged than the Level II results. These estimates indicated that the Level II results are roughly 47% less that the building damage predictions shown in the FEMA study and 9% less than the highway bridge damage estimates.

Table 253: FEMA - Current Study Damage and Loss Comparison

	Studies	
	FEMA Northeast	**Level II Northeast**
Light Wood Frame Collapses	120,002	63,242
URM Collapses	32,056	20,823
Mobile Home Collapses	31,123	19,490
Highway Bridges - At Least Moderate	1,656	1,511
Potable Water Breaks	65,795	43,320
Waste Water Breaks	52,038	34,262
Debris (thousands of tons)	26	16
Displaced Households	205,637	118,743
Temporary Housing	57,437	34,181
Casualties - Worst Case	61,657	35,487
Building Losses	$49.21	$32.90
Transportation Losses	$6.30	$4.44
Utility Losses	$12.50	$11.55
Total Direct Losses	**$68.0**	**$48.9**

Pipeline damage to potable water and waste water distribution systems is nearly twice as much in the FEMA study. Potable water and waste water lines are expected to incur 65,800 and 52,000 breaks, receptively, based on FEMA results, though this study estimates only 43,300 and 34,200 for these same values.

Various other loss values include debris generation, shelter requirements and injuries. Approximately 10 million tons more debris is generated by the FEMA study, which is a 63% increase over the debris value shown in this research. Regional shelter requirements shown in the FEMA study are roughly 75% greater than the values determined in the Level II analysis. Lastly, casualties incurred by the FEMA region are show increases similar those experienced by regional shelter requirements. Overall, the FEMA baseline study anticipates nearly twice as much damage as the Level II results for the northeast extension.

Regional losses show roughly the same trends as infrastructure damage. Building losses are nearly $33 billion, while FEMA baseline losses for buildings exceed $49 billion. Transportation and utility losses presented in the Level II analysis are 15%-33% less than those reported in the FEMA study of the northeast extension. It is critical to note here that both studies incorporate HAZUS-MH default pipeline assumptions for the northeast epicenter. Early discussions cite greater damage estimates with HAZUS-MH assumptions as oppose to regional network data. Based on this damage comparison the larger damage case is also assumed to incur greater losses and thus is used for comparisons with the FEMA study. When all loss components are totaled the FEMA study reports over $68 billion in regional loss, while the results of this study are only $48.9 billion. The FEMA baseline study of the northeast extension provides regional losses approximately 40% greater than the regionally results presented in this study of the northeast extension.

Further comparisons of regional loss values for each of the three fault extensions are detailed in Table 254. In every case the losses determined by FEMA are 40% - 65% greater than the results of this study. Both the studies indicate that the worst-case scenario is an earthquake on the southwest extension of the New Madrid Fault, as FEMA and this research show extreme loss values at this location of $77.1 and $50.5 billion, respectively. The only significant difference between these two scenarios is the version of liquefaction susceptibility map employed.

Table 254: Comparison of Regional Economic Losses for Three Fault Extensions

	Losses ($ billions)			
	Building	**Transportation**	**Utility**	**Total**
FEMA Northeast	$49.20	$6.30	$12.50	***$68.0***
Level II Northeast	$32.90	$4.44	$11.55	***$48.9***
FEMA Central	$52.60	$6.70	$11.00	***$70.3***
Level II Central	$28.68	$4.39	$9.80	***$42.9***
FEMA Southwest	$57.80	$7.30	$12.00	***$77.1***
Level II Southwest	$34.38	$5.04	$11.03	***$50.5***

Based on the results of the study conducted here it is necessary to investigate the impact of the liquefaction susceptibility map specifically. Since results for the updated liquefaction map already exist the only analyses required are those of the FEMA baseline region with the old liquefaction map in HAZUS-MH. By isolating the liquefaction map the regional sensitivity to that single factor is investigated in additional simulations using the aforementioned FEMA-developed hazard maps for the southwest fault extension.

Results from the subsequent analysis indicate that the liquefaction susceptibility map is indeed a major contributor to the difference in regional losses. Table 255 highlights the new results from the analyses with the original liquefaction map. The original FEMA study of the southwest epicenter appears on the first line and is followed by the results of the rerun of the FEMA SW scenario with the original liquefaction map. Since these results employ the same hazard (ground motion and liquefaction susceptibility) it verifies the original FEMA results. The 'Level II' values indicate the losses for the study region considered in this research. The difference in the additional Level II with the old (or original) liquefaction proxy indicates that this is indeed the reason that regional damage and loss values in this research are less than the values determined in the FEMA baseline study. Though the original FEMA analysis reports $2.5 billion more loss this is less than 5% total regional loss and can be considered negligible.

Table 255: Effect of Liquefaction Map and Proxy

	Losses ($ billions)			
	Building	**Transportation**	**Utility**	**Total**
FEMA Southwest	$57.80	$7.30	$12.00	**$77.1**
Level II Southwest w/ Old Liquefaction	$55.62	$7.23	$11.69	**$74.5**
Level II Southwest w/ New Liquefaction	$34.38	$5.04	$11.03	***$50.5***

8 Summary and Conclusions

8.1 Summary of Results

The different impact assessment cases considered in this report in conjunction with comparisons with the FEMA baseline and the CUSEC state-based assessments provide a wealth of information on the probable impact of a NMSZ earthquake. Whereas conclusions are drawn as results are presented in earlier sections, important conclusions are reiterated hereafter.

Based on the analyses conducted herein it is concluded that the incorporation of site affects and soil amplification intensifies ground motion. Peak ground acceleration increases for all three fault extension though this is most pronounced with the central fault extension as the maximum PGA value nearly doubles, from 0.67*g* to 1.25*g*. Peak ground velocities show trends similar to those exhibited by PGA values. The maximum PGV value resulting from a central extension event increases by roughly 60% when site affects are considered. All fault extensions show PGV increases of at least 25%, however. Short-period spectral acceleration values experience negligible changes when regional site affects are applied to the ground motion for both the northeast and central fault extensions. The southwest extension, however; shows a reduction in short-period spectral acceleration, from 2.6*g* in the default case to 1.5*g* in the improved case. Long-period spectral accelerations increase by sizeable margins as well, though the central extension scenario experiences the greatest increase in maximum value, from 0.8*g* to 1.5*g*.

The addition of liquefaction susceptibility further increases regional loss estimations over those experienced by the addition of site classes. Total direct economic losses double in some cases when liquefaction is considered. The inclusion of these factors permits the determination of the worst-case scenario for an earthquake on the New Madrid Fault. This worst-cased scenario occurs along the southwest extension of the fault and is estimated to generate $50.5 billion in regional losses.

Comparisons with the FEMA baseline study for the northeast extension illustrate the impact of ground shaking on loss and the related methods by which hazard is defined. The finite fault rupture model employed by FEMA and the USGS to determine ground motion shows substantially more intense shaking than the attenuations provided for the Central and Eastern U.S. is HAZUS-MH.

An investigation of the liquefaction susceptibility proxy indicates that using the original liquefaction map generates significantly higher regional losses. As was discussed earlier, the original liquefaction susceptibility proxy and map was reported to produce $77 billion in economic loss for the southwest extension. A check of this scenario reported $74.5 billion, which is roughly 3% less than the loss value determined by FEMA. This small difference may be considered negligible. Updating the liquefaction proxy and map produces much lower economic losses or only $50.5 billion for the southwest fault event. Incorporating a revised version of the liquefaction proxy and map reduces loss values by one-third.

The variation in regional losses exhibited by HAZUS-MH analyses completed with original and updated liquefaction maps highlights the uncertainty present in the determination of regional liquefaction susceptibility. Updating local liquefaction susceptibility values in specific areas reduced liquefaction potentials, permanent ground deformations for lateral spreading and settlement. Applying the revised version of the liquefaction susceptibility proxy and map results in less economic loss than that estimated in the FEMA study. Both maps do not account for permanent ground deformation due to lateral spreading, however, which is a significant deficiency in both maps. When these two impact assessments are evaluated and compared to one another though, they provide a range of loss values that can be used to bracket regional impacts and quantify uncertainty, whereas one individual assessment cannot.

The only inventory improvement used in this study is the ingestion of the pipeline data from the HSIP Gold dataset. Damage predicted using the HSIP data is lower than estimates based on the HAZUS default pipeline data. This is attributed to the observation that the HSIP data set does not include the delivery (local) distribution system, but rather the major pipelines only. HAZUS, on the other hand, assumes that the pipeline network coincides with the road network. HAZUS appears to be more conservative, though its relationship with the real pipeline network is unknown. Improving the HSIP data set is therefore the clear option to follow.

Replacing HAZUS fragilities by MAE Center-calibrated parameterized fragilities (Jeong and Elnashai, 2006) resulted in reduced damage for most structures but for light wood frames and some mobile homes, which show increased damage. Since light wood frames are numerous in the study region, the overall impact of using MAE Center fragilities is some increase in the estimated losses.

At this preliminary stage of the project, the most reliable economic impact estimates are summarized in Table 256. The economic losses and social impacts are likely to increase when the hazard, fragility and inventory are developed further, and additional aspects, such as traffic flow modeling, are accounted for.

Table 256: Regional Impact Assessment Summary Values

	Northeast	Central	Southwest
Fatalities	1,799	1,570	1,939
Buildings Losses	$32.9	$28.7	$34.4
Transportation Losses	$4.4	$4.4	$5.1
Utility Losses	$11.6	$9.8	$11.0
Total Direct Economic Losses	$48.9	$42.9	$50.5

Seismic risk assessment in the New Madrid Seismic Zone is still in its early days. Both the study completed herein and the FEMA baseline assessments should be considered preliminary work and points of reference for future studies. There is still much information to be gathered and incorporated into loss assessments.

8.2 Future Work

The analysis undertaken here included various updates to soil information as well as utility distribution network additions and building fragilities. Even though liquefaction susceptibilities were used and investigated these values remain suspect and the use of more reliable liquefaction information is warranted. Further updates to the bridge data with the assets present in the National Bridge Inventory are also needed. Various other inventory items would benefit from updated databases, including; essential facilities and their building types, hazardous materials, high-potential loss facilities, communications networks, power plants as well as many other transportation and utility networks component inventories. Additional inventory categories for regionally significant structures would provide more accuracy in loss modeling for the CEUS, such as major bridges and high-rise structures.

Future impact assessments will also benefit from the identification of specific inventory categories that are especially vulnerable to shaking. As was highlighted earlier, URMs are particularly susceptible to damage and collapse even when subjected to low levels of shaking. Significant damage sustained by these structures is the likely cause of a large portion of regional injuries and fatalities. As a result, future assessments will need to quantify the casualties resulting from URM damage and follow with mitigation strategies to reduce the social impacts of this type of damage.

The classification of regional seismic code levels also plays a crucial role in the determination of damage. As is shown in Figure 43, the moderate-code level is assigned to a portion of the study region. It is unlikely that construction in that area complies with moderate-code specifications and thus should be classified as low-code. Future impact assessments will classify the entire eight-state region as low-code to better reflect the actual construction practices of the central U.S. Updating this code-level classification will produce greater damage levels nearest the presumed New Madrid Fault which generates the most intense regional shaking values. In addition, direct economic losses in the area changed from moderate- to low-code will increase.

Yet another area of concern is the relationship between critical infrastructure components and areas of severe casualties. The performance and functionality of the transportation network and trauma centers will greatly affect the ability to aid severely injured residents of heavily damaged areas. Identifying potential locations of significant damage to transportation and utility networks and severe casualties will support planning efforts to mitigate these regional vulnerabilities and streamline response efforts.

Currently, HAZUS operates with a fire following earthquake model that is relatively simple and only considers peak ground acceleration and census tract building density. Since much of the eight-state region considered in the catastrophic planning effort for the NMSZ is rural a new model considering pipeline damage as well as regional shaking, construction type, number of fire breaks and extent of fire breaks may be useful.

Only hazard scenarios located along the presumed New Madrid Fault system are considered in this report. Future work, however, will include analyses of hazard scenarios along the Wabash Valley Fault with a magnitude of 7.1. This event generates its most intense shaking along the Illinois/Kentucky border. A second additional scenario is near St. Louis, Missouri, with a magnitude of 6.0. This event will likely generate the greatest damage and loss to the urban area of St. Louis, Missouri, and provide a worst-case for that city.

It has also been shown that the method by which earthquake hazard is characterized greatly affects impact assessment. Loss models would benefit from a sensitivity study that focuses on hazard characterization methods (point-source versus line-source for example). While the Mew Madrid Seismic Zone has no clearly defined faults but rather a broad area within which earthquakes are expected to occur investigations of fracture initiation and propagation will lead to the determination of better defined limits between which losses may credibly vary.

Further impact assessments shall be undertaken at the county level within the entire eight-state region. Individual worst-case scenarios will be identified for each state and earthquake impact assessments completed. Reporting of result data is required at the county-level to incorporate emergency planners at various levels within each state.

While the study detailed herein addresses several components of loss assessment numerous hazard, inventory and fragility parameters were not addressed at this early stage of the project. The following list delineates hazard, inventory and fragility components (some of which were investigated in this research) as well as regional demographics and loss modeling parameters that should be addressed in future earthquake impact assessments:

- Hazard
  - Refined site class maps
  - Refined liquefaction susceptibility maps
  - Refined landsliding maps detailing slope angles
  - Refined ground water depth maps
  - Various ground motion definition methods for determination of worst-case (most intense) ground motion
    - Point-source
    - Line-source
    - Area source
- Inventory

  - Updated general buildings stock per census tract by specific building and occupancy type by adding information regarding building counts, square footage, number of stories, seismic design level and year built
  - Develop point-wise general building data if time permits
  - Essential Facilities (Point-wise location data)
    - Each facilities is defined by seismic design level, year built, backup power capabilities as well as the number of available beds for medical care facilities and the number of fire trucks at each fire station
  - Transportation Systems
    - All highway and railway bridges require the definition of bridge length, scour index, skew angle and maximum single span length
    - Highway Segment, Railway Segment and Airport Runway Segment length and width
    - Facilities comprising the transportation systems require point-wise location data as well as the year each facility was built, seismic design level, building type (structure type), backup power capabilities and details regarding the anchoring of fuel tanks and equipment
  - Utility Systems
    - Pipeline networks necessitate pipeline lengths, qualification as ductile of brittle pipe and pipe diameter for proper damage determinations in HAZUS
    - All facilities, pumping stations, control vaults and stations, plants, etc. require information about building (structure) type, seismic design level, year built, backup power capabilities and the anchoring of tanks and equipment
  - Hazardous Materials Facilities and high-Potential Loss Facilities
    - Chemicals and amounts per site
    - Anchoring of tanks and equipment
  - Military Installations
    - Number and types of buildings on site, etc.
- Fragilities
  - For all specific building types
  - For transportation components (Bridges, Facilities and Networks)
  - For utility components (Facilities and Networks)
- Demographics and Social Loss Models
  - Updated regional demographics for age, gender, income, ethnicity, etc.
  - Regional models for displaced persons and temporary housing
- Other Loss and Restoration Models
  - Regional restoration functions for functionality estimates of regional facilities and networks
  - Regionally adapted direct and indirect economic loss models

The above list provides a guide to the data and models that should be collected and ingested into HAZUS for more accurate and reliable loss assessment results. Additional assessments for individual states should be considered as well. While the regional losses detailed herein addressed the northern and southern fault extremes, individual state analyses would benefit from a scenario occurring closest to the state of interest. This type of earthquake impact assessment will provide state emergency management agencies and aid organizations with the worst-case damage, loss and functionality estimates for their individual state.

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Appendix A: Uncertainties in Loss Assessment Results

Over the course of this investigation numerous deficiencies in HAZUS-MH are identified which call into question the reliability of results and calculations completed by the program. One major concern is the cut-off distance applied to point-source earthquakes in HAZUS-MH. All attenuations are cut-off at a distance of 200km from the epicenter, after which a value of zero is assigned to all ground motion values in these census tracts. This assignment of zero PGA produces random damage to essential facilities. By assigning random damage probabilities some essential facilities that experience minor ground shaking ($< 0.05g$) may be assessed probabilities greater than 80% for the at least moderate damage state, for example. If this method of ground motion definition is applied over a large area, more than 100 or 150 counties for instance, the high damage likelihoods will impact regional building losses significantly.

The hazard definition methodology plays a critical role in the determination of regional damage, loss and systems functionalities. It has been shown that the difference between a point-source hazard generation method and a line-source, or fault-rupture, hazard generation method yield very different regional direct and induced damage as well as social and economic losses. The point-source method used in this research is based on the combined weighting of four attenuation functions determined appropriate for the central and eastern U.S. These attenuations estimate the propagation of ground shaking from a single point rupture, generating concentric circles of equal shaking, when site affects are not included. The fault-rupture methodology employed in the referenced FEMA baseline study, as well as in the improved Level I and Level II analyses models the breaking of a fault segment. Rather than a single rupture, the line-source estimates the shaking produces by a continuous rupture along a specific length of the fault. Since so little is know about the behavior and rupture mechanism of the New Madrid Fault various methods maybe used to define the source excitation in this area. The uncertainty present in the regional hazard definition propagates to all facets of earthquake impact assessments all damage, loss and functionality values are related to regional ground motion in some manner.

Additional program deficiencies exist in the fire following earthquake model which is based on fire damage and spread for urban Japan. This model employs urban building density, street widths and fire propagation (Scawthorn, Eidinger & Schiff, 2005). Variables for the quantity and width of fire breaks, or streets in the Hamada model, are grossly different for an urban setting than a rural setting. Since most of the CEUS region investigated here is rural, fire breaks and building density factors are not necessarily applicable. The fire model in HAZUS-MH is closed source, indicating that these parameters relating to the ignition and spread of fire. There is no opportunity to improve the model to represent the characteristics of the central and eastern U.S. In addition, the fire model can not be refined for larger urban areas and very rural locations within the region of interest.

Building damage values experience inconsistencies when rounded off at the census tract level. Examining the general building stock damage by building count and square footage for any level if analysis undertaken herein it reveals that the total number of buildings or total square footage is slightly different between damage assessments for each fault extension. The Level I analysis, for example, shows 2,754,457 light wood frame structures with the northeast event, 2,754,522 for the central event and 2,754,464 for the southwest event. These differences are less than 0.005% of the light wood frame inventory, though are still noticeable. This trend applies to the major building types discusses in this study at all levels of analysis.

Additional problems are encountered when externally provided inventory is added. Numerous program crashes and bugs prohibit the proper importing of data as well as the inaccurate reading of data projections from ArcGIS. It is common for HAZUS-MH to require several attempts at importing the same data prior to its proper recognition and assignment within the program. Furthermore, when attempting to remove inventory items is unsuccessful in numerous cases. Even when calculations show that the removed inventory is no longer present HAZUS-MH still displays this deleted inventory in its inventory windows.

Region sizes are also inhibited by the limited computing capability of HAZUS-MH. Only regions less than two gigabytes in size are permitted by the default HAZUS-MH server. It is stipulated that SQL Server may be added to permit the use of larger regions, though computation time is still extremely long and inhibits the number of analyses that can be completed in a given time frame.

HAZUS-MH does not have a feature to determine assessment uncertainty, but rather suggests conducting several analyses with varied input parameters. This larger sensitivity study not only requires considerable time, it also prevents the determination of uncertainty to be quantified in one file. Sensitivity to a single variable or a group of variables must be analyzed outside of HAZUS-MH, which also requires substantial amounts of time. Also, some form of uncertainty characterization would provide a range of loss values that are expected instead of one single regional loss number that provides the illusion of a single, definitive loss value for a seismic event.

Essential facilities damage and losses are based on several key variables that define structural type. The former is defined in HAZUS-MH via two categories; structure type and seismic design class. The structure type classifications for essential facilities are based on regional assumptions rather than actual field surveys. These assumptions stipulates that nearly all CEUS hospitals are precast concrete tilt-up structures with shear walls, PC1, with a small percentage specified as low-rise steel frames, S1L. All police and fire stations, as well as schools are assumed to be low-rise unreinforced masonry structures. In addition all essential facilities are classified as pre-code or moderate-code in a corresponding manner to the general building stock (See Figure 43). This is not the case for actual regional essential facilities and could be improved.

Yet another area of concern in the analyses completed in this study is the level of damage seen in ferry facilities of the transportation system. Every earthquake scenario, regardless of epicenter location, generated complete damage of all ferry facilities. One ferry facility lies north of St. Louis, Missouri, which would not be expected to incur complete damage from an event on the southwest extension. HAZUS-MH, however; predicts complete damage of this northern facility for a seismic event in northeastern Arkansas. Every scenario was assessed the loss value associated with complete damage of all four facilities which is not likely to be the case in an actual event, and raises questions about the HAZUS-MH damage and loss model for these facilities, and others, with regards to their accuracy and performance.

With the great amount of uncertainty present in HAZUS-MH the program would benefit from options to reduce uncertainty and investigate mitigation options. Adding retrofitting options to regional infrastructure components such as buildings and bridges permits desktop studies to investigate the impact of numerous seismic retrofits without the added expense of trial and error retrofitting in the field. This means that numerous retrofit options for a single bridge or building type may be considered in an analytical loss assessment study and the best option determined based on these results as oppose to applying an assumed best-retrofit option and waiting for an actual event to check these suggestions.

Previous comparisons of externally calculated ground motion and HAZUS-MH calculated ground motion within the 200km source-to-site distance show and overestimation of ground motion, particularly near the epicenter. Previous the ground motion determined within HAZUS and externally were compared (See Accuracy of Hazard Maps section). The northeast epicenter external calculations assign a maximum regional PGA of 0.9*g* in the default case, which occurs at the census tract nearest the specified epicenter. HAZUS-MH internally calculated ground motion assigns a much higher regional maximum PGA of 1.48*g*. The difference between these two calculations is roughly 0.6*g*. A reduction in maximum shaking value of this magnitude will impact the damage to tracts nearest the epicenter significantly. Greater damage generates higher losses to buildings, transportation and utility systems, as well as altering social impacts and induced damage. While the margin or error decreases as the source-to-site distance increases, internally calculated ground motions are still higher. This concern, as well as the aforementioned concerns, call into questions the practicality and reliability of HAZUS-MH. In light of this reliability discussion and the results presented as study, conclusions, values and estimates should be taken as a median values, from which actual losses will differ.

The number of census tracts is a critical factor in the region determination as well. FEMA encountered problems with map attachments and analyses in HAZUS-MH that are attributed to the region size exceeding the suggested limit. Attempts were made to introduce SQL Server 2005 in place of the suggested SQL Server 2000 which permits the use of regions larger than 2GBs. After much collaboration with PBS&J, the developers of HAZUS-MH, it was determined that SQL Server 2005 is not compatible with HAZUS-MH MR2 due to updates made in the 2005 edition of SQL Server. Without the use of an external database management system it is necessary to work within the limitations of HAZUS-MH's default server. The region used in this research comprises approximately 1,900 census tracts, which is less than the recommended region size limit and permits analysis with the HAZUS-MH default server.

Appendix B: HAZUS-MH Databases for New Madrid Seismic Zone Loss Assessment

Files contained on CD:

RecheckFEMAsouthwest.hpr: This is a rerun of the original FEMA baseline study for the southwest extension of the New Madrid Fault. Hazard maps include the shaking maps developed by FEMA/USGS for the southwest extension, which are found on this CD in the 'Hazard Maps' folder then the 'Improved Level I Ground Motions' folder with file name "Swshakemaps.mdb." In addition the "LiquefactionOriginal.mdb" liquefaction susceptibility map was employed. This map is also found in the 'Hazard Maps' folder on the CD.

CONTENTS OF 'Hazard Maps' FOLDER:

LiquefactionOriginal.mdb: This is the original liquefaction susceptibility map developed based on a liquefaction proxy that is discussed in the body of report. It was used for the FEMA Baseline study and a recheck scenario that is also included on this CD.

LiquefactionUpdated.mdb: An updated version of the original liquefaction susceptibility map and proxy. This map is used for all Level II analyses in this report.

CONTENTS OF 'Level I Ground Motions' FOLDER:

NortheastDefault.mdb: All hazard maps used to determine losses for an earthquake along the northeast extension of the New Madrid Fault. Soil amplification of ground motion is not included. Developed using CEUS attenuations prescribed in HAZUS-MH.

CentralDefault.mdb: All hazard maps used to determine losses for an earthquake along the central extension of the New Madrid Fault. Soil amplification of ground motion is not included. Developed using CEUS attenuations prescribed in HAZUS-MH.

SouthwestDefault.mdb: All hazard maps used to determine losses for an earthquake along the southwest extension of the New Madrid Fault. Soil amplification of ground motion is not included. Developed using CEUS attenuations prescribed in HAZUS-MH.

CONTENTS OF 'Improved Level I Ground Motions' FOLDER:

NEshakemaps.mdb: All hazard maps used to determine losses for an earthquake along the northeast extension of the New Madrid Fault. Soil amplification of ground motion is included with the addition of site affects. Maps developed by FEMA/USGS with finite-fault model for northeast extension of New Madrid Fault system.

NM-RT-HAZUS.mdb: All hazard maps used to determine losses for an earthquake along the central extension of the New Madrid Fault. Soil amplification of ground motion is included with the addition of site affects. Maps developed by FEMA/USGS with finite-fault model for central extension of New Madrid Fault system.

SWshakemap.mdb: All hazard maps used to determine losses for an earthquake along the southwest extension of the New Madrid Fault. Soil amplification of ground motion is included with the addition of site affects. Maps developed by FEMA/USGS with finite-fault model for southwest extension of New Madrid Fault system.

CONTENTS OF 'HSIP Pipelines' FOLDER:

FEMApipelines.mdb: Regional natural gas and oil pipelines extracted from the HSIP GOLD dataset from 2005.

PipelinesNortheast.hpr: HAZUS analysis of HSIP pipeline damage with Improved Level I ground motion for the northeast extension and updated liquefaction map.

PipelinesCentral.hpr: HAZUS analysis of HSIP pipeline damage with Improved Level I ground motion for the central extension and updated liquefaction map.

PipelinesSouthwest.hpr: HAZUS analysis of HSIP pipeline damage with Improved Level I ground motion for the southwest extension and updated liquefaction map.

CONTENTS OF 'Building Fragilities' FOLDER:

Southwest GBS Inventory.xls: Collection regional building counts and square footages delineated by specific building type taken from the Level II analysis of the southwest fault extension.

Fragility Conversion Factors.xls: Spreadsheet detailing the development of general building stock damage conversion factors for all specific building types, codes levels and damage states. Fragility functions developed by the MAE Center.

GBS Fragility Conversion Southwest.xls: Modification of damage to regional general building stock by building count using MAE Center-developed building fragilities. Damage estimates are performed for the southwest extension Level II hazard scenario.

CONTENTS OF 'Level I' FOLDER:

NortheastLevel1.hpr: Level I analysis of northeast epicenter event. This region employs northeast default ground motions also found on this CD.

CentralLevel1.hpr: Level I analysis of central epicenter event. This region employs central default ground motions also found on this CD.

SouthwestLevel1.hpr: Level I analysis of southwest epicenter event. This region employs southwest default ground motions also found on this CD.

CONTENTS OF 'Improved Level I' FOLDER:

NortheastImprovedLevel1: Improved Level I analysis of northeast fault extension with FEMA/USGS ground motions for the northeast extension. These ground motions are included on this CD.

CentralImprovedLevel1: Improved Level I analysis of central fault extension with FEMA/USGS ground motions for the central extension. These ground motions are included on this CD.

SouthwestImprovedLevel1: Improved Level I analysis of Southwest fault extension with FEMA/USGS ground motions for the Southwest extension. These ground motions are included on this CD.

CONTENTS OF 'Level II' FOLDER:

NortheastLevel2.hpr: Level II analysis of northeast fault extension with FEMA/USGS ground motions for northeast extension. Also, updated liquefaction susceptibility map is used. All these hazard maps are included on this CD.

CentralLevel2.hpr: Level II analysis of central fault extension with FEMA/USGS ground motions for central extension. Also, updated liquefaction susceptibility map is used. All these hazard maps are included on this CD.

NortheastLevel2.hpr: Level II analysis of southwest fault extension with FEMA/USGS ground motions for southwest extension. Also, updated liquefaction susceptibility map is used. All these hazard maps are included on this CD.

Appendix C: Counties Experiencing Damage

All counties in the study region experience some form of damage resulting in loss. Whether from building, transportation and/or utility damage, no county in the 230-county study region is exempt from damage resulting from shaking in the new Madrid Seismic Zone. The counties in the study region are listed below, by state:

Alabama

Colbert
Cullman
Fayette
Franklin
Lamar
Lauderdale
Lawrence
Limestone
Marion
Morgan
Walker
Winston

Arkansas

Arkansas
Baxter
Clay
Cleburne
Cleveland
Craighead
Crittenden
Cross
Desha
Faulkner
Fulton
Grant
Greene
Independence
Izard
Jackson
Jefferson
Lawrence
Lee
Lincoln
Lonoke
Mississippi
Monroe
Phillips
Poinsett
Prairie
Pulaski
Randolph
St. Francis
Sharp
Stone
Van Buren
White
Woodruff

Illinois

Alexander
Bond
Calhoun
Clark
Clay
Clinton
Crawford
Edwards
Effingham
Fayette
Franklin
Gallatin
Greene
Hamilton
Hardin
Jackson
Jasper
Jefferson
Jersey
Johnson
Lawrence
Macoupin
Madison
Marion
Massac
Monroe
Montgomery
Perry
Pope
Pulaski
Randolph
Richland
Saint Clair
Saline
Union
Wabash
Washington
Wayne
White
Williamson

Indiana

Daviess
Dubois
Gibson
Greene
Knox
Pike
Posey
Spencer
Sullivan
Vanderburgh
Warrick

Kentucky

Ballard
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
Chickasaw
Coahoma
Desoto
Grenada
Itawamba
Lafayette
Lee
Marshall
Monroe
Panola
Pontotoc
Prentiss
Quitman
Sunflower
Tallahatchie
Tate
Tippah
Tishomingo
Tunica
Union
Yalobusha

Missouri

Audrain
Bollinger
Boone
Butler
Callaway
Cape Girardeau
Carter
Cole
Crawford
Dent
Douglas
Dunklin
Franklin
Gasconade
Howell
Iron
Jefferson
Lincoln
Madison
Maries
Miller
Mississippi
Montgomery
New Madrid
Oregon
Osage
Ozark
Pemiscot
Perry
Phelps
Pike
Pulaski
Reynolds
Ripley
Saint Charles
Saint Francois
Saint Louis
Saint Louis
Sainte Genevieve
Scott
Shannon
Stoddard
Texas
Warren
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
Maury
McNairy
Montgomery
Obion
Perry
Robertson
Shelby
Stewart
Tipton
Wayne
Weakley
Williamson