Comprehensive Seismic Loss Assessment for the State of Illinois

Interim Report

Report No. 07-01

Submitted to

Illinois Emergency Management Agency

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1. Introduction

1.1 Motivation for this Study

The New Madrid Seismic Zone (NMSZ) is the most earthquake prone area of the United States east of the Rocky Mountains. The NMSZ is located in the central Mississippi Valley. It is estimated that in the region, there is a 90% chance of a magnitude 6 or 7 event occurring in the next 50 years (Hildenbrand et al., 1996). In the NMSZ, more than 3000 earthquakes have been recorded since 1974, the year network monitoring of seismic activity began. Fortunately, none of these earthquakes exceeded a magnitude greater than 5.0, and most occurred unnoticed by citizens (Johnston and Schweig, 1996). The underlying geology of the NMSZ is such that an earthquake of magnitude 7, an equal magnitude of the Loma Prieta earthquake in California, would affect an area many times larger than that affected in the Loma Prieta earthquake (Hildenbrand et al., 1996).

Several historic, highly-damaging earthquakes have occurred in the Central and Eastern United States (CEUS). The most notable are the 1886 Charleston, South Carolina Earthquake and the series of 1811-1812 New Madrid, Missouri earthquakes.

The 1886 Charleston earthquake was one of the strongest earthquakes to occur in eastern North America. The earthquake occurred on September 1, 1886 and had an estimated magnitude of 7.3. It caused 60 deaths and damaged or destroyed nearly every structure in the City of Charleston and the surrounding area. The event caused large fissures and craterlets to form in the ground. The ground deformation caused extensive railroad track damage in the Charleston region. The earthquake caused structural damage to buildings as far away as central Ohio and was felt as far away as Boston, Milwaukee, and Cuba (Stover and Coffman, 1993).

The most powerful earthquakes ever to occur in the continental United States took place in the NMSZ during the winter of 1811-1812. This series of earthquakes consisted of three major events of magnitude 8.0 or larger and many aftershocks of significant magnitude. The magnitudes of the 1811-1812 events were determined using historical accounts from witnesses both near and far from the earthquake epicenters, preserved effects from the earthquakes, such as liquefaction features, current seismicity, and the structure of the Earth's crust in the 1811-12 fault zone (Johnston and Schweig, 1996). The earthquakes destroyed much of what existed in the region around the NMSZ, and landscape still remains changed. For example, the route of the Mississippi River was changed over a local area, and Reelfoot Lake in Tennessee was created because of these seismic events (Hildenbrand et al., 1996).

In the early 1800s, the area surrounding the NMSZ had very few structures and was scarcely populated. Today, the region is more densely populated, and the reoccurrence of an event similar to the 1811-12 earthquakes would devastate the region. Current estimates of losses for the region are in the range of $60 billion to $80 billion in direct losses only. The safety of many people would be threatened, and the region would billions of dollars of damage. It is important to study how the repeat of a similar event would affect the region near the NMSZ today so that states and localities can be prepared to react to such an event. The results of this study will be used to determine vulnerability of the infrastructure in the State of Illinois, prioritize mitigation efforts in the state, quantify damage in economic terms, and aid in development of public awareness projects.

1.2 Earthquake Loss Assessment

Systematic loss assessment studies began after the 1971 San Fernando earthquake. The first studies focused on casualties, injuries, and the state of emergency health care as a result of a given scenario earthquake. Recent loss assessment studies have been funded by insurance or government agencies. Current loss assessment studies for government agencies emphasize the number of casualties and the damage and functionality of lifeline systems, such as roads and utility systems. These results aid in emergency response planning. Studies performed for the insurance industry estimate losses to the general building stock and economic losses (FEMA, 1994). Today, loss estimation can be used to help predict the type and amount of emergency response required after an earthquake, to help develop post-earthquake recovery plans, and to help make decisions that can mitigate the effects of an earthquake (FEMA, 2006a).

Several methodologies were developed previous to HAZUS to perform seismic loss assessments. The methodologies were developed for different purposes, and therefore have a large variation in scale and complexity. In 1972, a seismic loss study was performed by the National Oceanic and Atmospheric Agency (NOAA) in which losses to the San Francisco Bay area were assessed for the Federal Office of Emergency Preparedness (FOEP). The results would be used for response and recovery planning, so this study primarily focused on injuries and losses to medical facilities. This study contains many medical-related estimates, but does not mention the general building stock and contains very little information about losses to other types of emergency facilities. Other studies contain no injury or medical facility loss estimates, such as a study performed in 1987 of Portland, Oregon, which focuses completely on water and wastewater utility systems (FEMA, 1994).

Some aspects of loss estimation are relatively uniform across most studies. A majority of studies have included the use of attenuation relationships, including the effect of site classes, to calculate the ground motion caused by a scenario earthquake. Many studies have ignored facilities with high potential losses, such as dams, refineries, and chemical plants. Other studies have determined, for example, which dams are subjected to the most risk, but did not study the flooding and damage due to inundation. Facilities containing hazardous materials have often been ignored (FEMA, 1994).

FEMA developed a list of key features that should be included in any regional loss study. These features include a hazard model, site-soil effects, liquefaction, landslide, fault rupture, fire, flood, hazardous material release, general buildings, lifelines, high potential loss facilities, critical and emergency facilities, homelessness, economic impact, and complete inventory. Very few previous loss estimation methodologies calculated ground motion internally. A complete inventory is considered to be one that contains inventory in all three categories of dwellings, lifelines, and critical facilities. FEMA's loss estimation methodology HAZUS was developed based on these requirements (FEMA, 1994).

1.3 HAZUS Overview

HAZUS, which stands for hazards-U.S., is a loss estimation methodology. HAZUS estimates social and economic losses to a user-defined region caused by a user-defined scenario earthquake. The scenario earthquake is an event defined by its magnitude and location. The steps in estimating losses include inventory collection and hazard definition, which are followed by a hazards impact assessment. The types of losses are quantitative estimates, estimated damage, estimated functionality losses, and effects of induced hazards. Quantitative estimates include cost of damage to buildings, both structural and non-structural, costs due to loss of function, numbers of casualties and injuries, tons of debris generated, and displaced persons. The damage is estimated as the probability that a facility, building, or class of buildings reaches the limit states of slight damage, moderate damage, extensive damage, or complete damage. Loss of function estimates are the percent operational estimates for facilities and lifeline system components at several time periods following the scenario earthquake. Induced hazards include fires, flooding, and hazardous material spills.

1.3.1 HAZUS Level 1 Analysis

A HAZUS level 1 analysis involves using only the default models and data provided in the loss estimation tool. The default databases in HAZUS include an inventory of the general building stock, essential facilities, transportation lifeline systems, utility lifeline systems, and high potential loss facilities. The default data also contains population distribution data, repair costs for facilities and lifeline components, and some economic information for the study region. Liquefaction and landsliding are ignored and it is assumed the study region consists of one uniform soil type. Uncertainty is large in a level 1 analysis, but this level of analysis requires very little user input because the user does not need to collect and implement improved inventory data or parameters. The required user inputs for a HAZUS level 1 analysis are the study region definition (any combination of states, counties, or census tracts), scenario earthquake definition (magnitude and location), and requests for the desired outputs. A level 1 analysis is most suitable for preliminary studies and basic comparisons between multiple regions. The HAZUS level 1 analysis used in this study used all default inventory and parameters, but user-defined ground motion maps were used to define the hazard. The implementation of these hazard maps can be found in the hazard definition section of this report.

1.3.2 HAZUS Level 2 Analysis

A HAZUS level 2 analysis involves the improvement of the default inventories and parameters. The quality of loss estimation results depends highly on the quantity, but more importantly, the quality of user supplied data. The data that can be input for a level 2 analysis includes soil map, which are be used to determine ground motion, liquefaction susceptibility maps, the distribution of floor area in each occupancy class in each census tract, the distribution of model building type in each occupancy class, essential facility inventory, utility and transportation lifeline inventory, local construction costs, local economic data, demographic data, inundation maps, high potential loss facility inventory, and hazardous material facility inventory.

1.3.3 HAZUS Modules

The HAZUS methodology is made up of several interdependent modules. The modules add flexibility to HAZUS because they allow the user to refine the data only in individual, selected modules, therefore giving flexibility the program and allowing for different levels of analysis. The user can choose to only run the modules of interest when setting up the analysis. The option to use only the necessary modules needed to produce the user-requested results can save significant program computation time.

1.3.3.1 Potential Earth Science Hazard Module

The potential earth science hazard module estimates ground shaking and ground failure, which includes liquefaction, landslides, and surface fault rupture, caused by the user-specified scenario earthquake. The ground motion is estimated using attenuation relationships that are built into the loss estimation tool or that can be specified by the user or by built-in probabilistic ground motion maps. The ground motion can also be defined by user-defined ground motion maps, which are used to define the hazard in all parts of this study.

1.3.3.2 Inventory Module

The inventory module contains data on the general building stock, essential facilities, transportation lifeline systems, utility lifeline systems, and high potential loss facilities. The general building stock is composed of 36 model building types, which specifies the materials and construction of a building. The buildings in HAZUS are assigned one of 33 occupancy classes, which define the building use, such as different categories of residential, commercial, or industrial uses. Data for individual buildings in the general building stock does not exist in HAZUS; instead, a square footage estimate for each building type-occupancy class combination is assigned to each census tract in the study region. The inventory for essential facilities, such as schools, medical care facilities, and emergency response facilities contains data for each individual facility. The data in HAZUS inventory for transportation lifeline systems includes the facilities and components of highway systems, railway systems, bus systems, ports, and airports. Utility lifeline systems include electric power, waste and potable water systems, communications, and natural gas system components.

1.3.3.3 Direct Damage Module

The direct damage module uses output of the potential earth science hazard module and the data of the inventory module to estimate physical damage to the general building stock, essential facilities, transportation lifeline systems, utility lifeline systems, and high potential loss facilities. The direct damage results are in the form of probabilities of each of the damage states (none, slight, moderate, extensive, and complete) for each type of building, facility, or system component. For the general building stock, direct damage includes both structural and non-structural damage.

1.3.3.4 Induced Damage Module

The induced damage module estimates secondary events, such as fires, debris generated, and dam failure and the resulting inundation. The debris estimate utilizes the damage results of the direct damage module and the building square footage of the inventory module.

1.3.3.5 Direct Social Losses Module

The outputs of the direct social losses module are quantitative estimates of casualties, injuries, displaced households, and short-term shelter needs. The casualty and injury estimates are determined for the three earthquake event times: day, night, and commute time. The results from this module are based on the results from direct damage module.

1.3.3.6 Direct Economic Losses Module

The direct economic loss module estimates direct economic consequences (repair and replacement costs) to repair the physical damage incurred to buildings and lifeline system components. The economic loss estimates of this module depend on the damage estimated by the direct damage module.

1.3.3.7 Indirect Losses Module

The indirect losses module estimates the long-term economic consequences caused by the direct economic losses. Such economic consequences include losses due to unemployment, reduced tax revenues, and lost income in the study region. The estimates are based on a synthetic economy, which is an extremely simplified model of the regional economy. The HAZUS Technical Manual recommends that changes to this module should involve input from an economist.

1.3.4 Uncertainties in HAZUS Loss Estimation

Every loss estimation methodology contains sources of uncertainty. The uncertainties are due to approximations used for the analysis and the limited information known about earthquakes and the behavior of structures during such events. Sources of uncertainty in HAZUS include incomplete building, lifelines, or demographic inventories and estimated economic or fragility parameters.

Large uncertainties are inherent in earthquake loss assessment; especially for the mid-America region by any earthquake loss estimation methodology. This is because the available damage data from past earthquakes is all but nonexistent. HAZUS has been calibrated using several earthquake scenarios in California. In these cases, HAZUS has given reasonable estimates of total losses but has given less credible detailed results. The detailed results are greatly affected by the accuracy of the inventory data. Although HAZUS can estimate damage to individual buildings, the damage results should be considered to be the average for a set of like buildings. The default inventory for the lifelines are less complete than the inventory for the general building stock and are very simplified. For example, there is no real pipeline data in the default utility system database. The user must keep in mind that HAZUS may give more accurate loss estimates for some inventories than others (FEMA, 2006a).

It is unlikely that the next earthquake to affect the region of interest will be the scenario earthquake that was utilized in any given loss estimation study. The magnitude, location, ground motions, and ground deformation will be different than what is predicted by a scenario event. This is especially relevant in the study region of Illinois because events are very infrequent, and consequently the seismicity in the Mid-America region is not fully understood.

Much uncertainty exists in the seismic resistance of the elements of the built environment in the study region. The buildings and other structures were constructed over many years and consequently were designed under various building codes, which cause much uncertainty in the seismic resistance of the structures in the inventory. The knowledge of building damage given ground motions is not complete, adding a level of uncertainty to the damage estimates. In addition, the structural system (building type) is needed to assess damage. In the case of the general building stock, in HAZUS, the number of buildings in each building type in a given census tract are inferred from the number of buildings in each occupancy class. The estimations in the conversion from occupancy class to building type with HAZUS add uncertainty to the damage estimates in this report.

2. Overview of the Inventory for the State of Illinois

The State of Illinois contains 102 counties, 2,964 census tracts, and a land area 56,264 square miles. The state has a population of over 12 million people and over 4.5 million households. HAZUS estimates that there are 3,551 buildings in the State of Illinois with a total building replacement value of $838 billion dollars, excluding contents. Approximately 98.00 % of the buildings are associated with residential housing. The replacement value of the transportation and utility lifeline systems is estimated to be $158 billion and $92.5 billion, respectively.

2.1 General Building Stock

Seventy-two percent of the general building inventory is of wood frame construction. The remaining 28% of the building inventory is distributed between the all other building types. The distribution of the dollar exposure for the general building stock is shown in Table 1. The replacement costs for residential, commercial, industrial, and institutional buildings were derived from RSMeans Square Foot Costs 2002 for (HAZUS TM Section 5.1.12.2).

Table 1: Distribution of Building Stock Dollar Exposure

Building Stock Dollar Exposure By General Occupancy (thousands of $)	
Residential	685,624,149
Commercial	110,115,375
Industrial	25,899,765
Agriculture	1,843,178
Religion	6,806,497
Government	1,892,282
Education	5,501,611
Total	837,682,857

2.2 Critical Facilities

HAZUS defines critical facilities in the two groups of essential facilities and high potential loss facilities. Essential facilities include hospitals, medical clinics, schools, fire stations, police stations and emergency operations facilities. High potential loss facilities include dams, levees, military installations, nuclear power plants and hazardous material sites.

According to HAZUS, the State of Illinois has 227 hospitals in the region with a total bed capacity of 42,983 beds. There are 5,283 schools, 1,007 fire stations, 866 police stations and 149 emergency operation facilities in Illinois. The HAZUS default inventory for the State of Illinois contains 1,255 dams. Of these, 154 of the dams are classified as 'high hazard'. The HAZUS default dam database is from the National Inventory of Dams database (FEMA, 2006b). The inventory also includes 4,870 hazardous material sites and 7 nuclear power plants.

The HAZUS default inventory for schools and medical facilities are shown for the State of Illinois in Figure 1 and Figure 2, respectively.

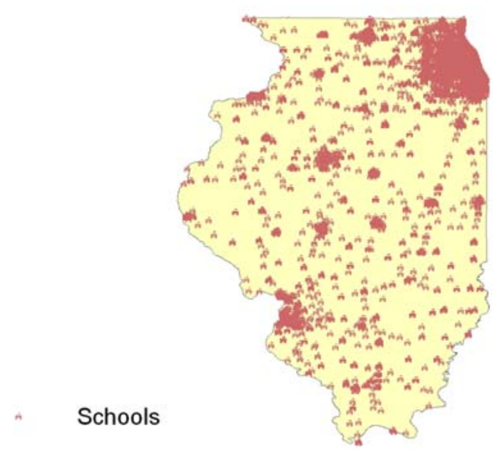


Figure 1: School Inventory

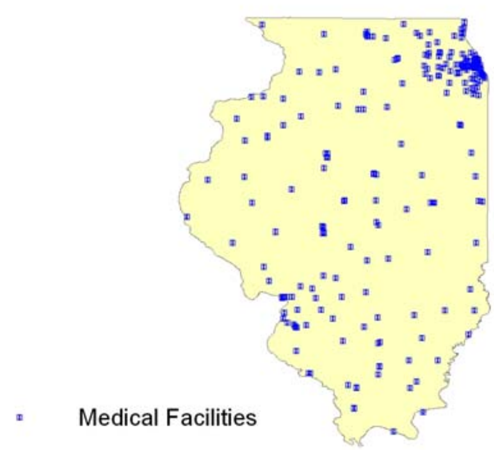


Figure 2: Medical Facilities Inventory

The HAZUS default inventory for fire stations and police stations are shown for the

State of Illinois in Figure 3 and Figure 4, respectively.

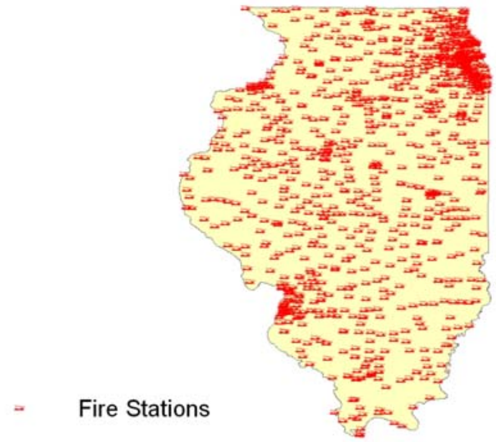


Figure 3: Fire Station Inventory

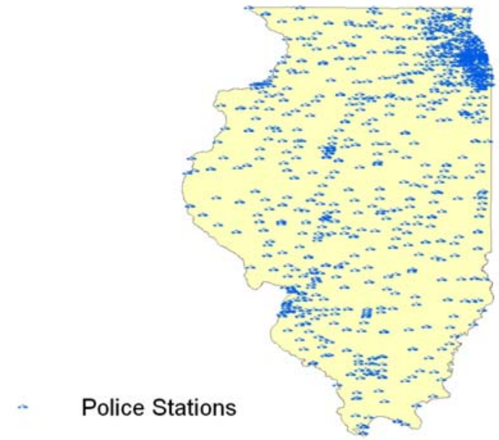


Figure 4: Police Station Inventory

The HAZUS default inventory for facilities containing hazardous materials and emergency operation centers are shown for the State of Illinois in Figure 5 and Figure 6, respectively.

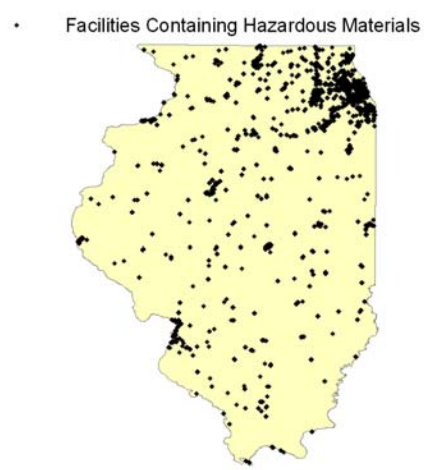


Figure 5: Hazardous Materials Inventory

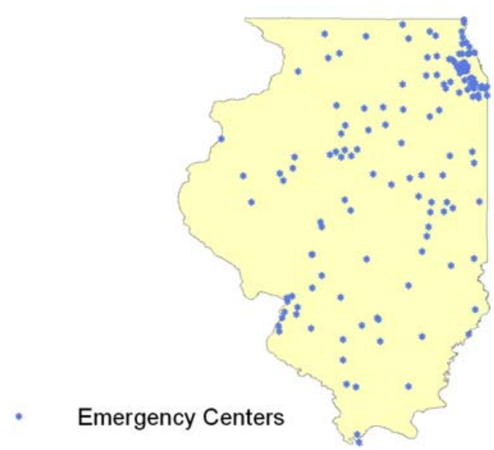


Figure 6: Emergency Center Inventory

2.3 Lifeline Systems

The lifeline inventory includes transportation and utility lifeline systems. The transportation system includes highways, railways, light rail, bus, ports, ferry and airports. The utility system includes potable water, wastewater, natural gas, crude & refined oil, electric power and communications. The total value of the lifeline inventory is over $250 billion. The lifeline inventory includes approximately 23,285 kilometers of highways, 22,854 bridges, and 530,795 kilometers of pipes. When pipelines are not explicitly imported into the loss estimation tool, their length is calculated based on the total road length in the study region.

2.3.1 Transportation Systems

The transportation systems inventory is summarized in Table 2. The highway transportation system contains nearly 23,000 highway segments and over 4,000 highway bridges. The highway system has the largest replacement value of all the transportation systems, followed by the airport transportation system.

Table 2: Transportation System Inventory

System	Component	# locations/ # Segments	Replacement value (millions of dollars)
Highway	Bridges	22,854	21,107.01
	Segments	4,333	95,066.33
	Tunnels	0	0.00
		Subtotal	**116,173.34**
Railways	Bridges	963	110.98
	Facilities	285	689.64
	Segments	8,441	11,844.99
	Tunnels	0	0.00
		Subtotal	**12,645.61**
Light Rail	Bridges	38	4.80
	Facilities	0	0.00
	Segments	30	124.88
	Tunnels	0	0.00
		Subtotal	**129.67**
Bus	Facilities	101	122.20
		Subtotal	**122.20**
Ferry	Facilities	2	2.42
		Subtotal	**2.42**
Port	Facilities	438	983.49
		Subtotal	**983.49**
Airport	Facilities	624	3,774.89
	Runways	705	24,321.65
		Subtotal	**28,096.54**
		Total	**158,153.27**

2.3.2 Utility Systems

The utility systems inventory is summarized in Table 3. No distribution lines or pipelines are included in the HAZUS default inventory for any of the utility systems. The largest and most costly of the utility systems is by far the wastewater system, which is followed by the electrical power system and the potable water system.

Table 3: Utility System Inventory

System	Component	# Locations / Segments	Replacement value (millions of dollars)
Potable Water	Distribution Lines	NA	5,307.95
	Facilities	242	8,945.05
	Pipelines	0	0.00
		Subtotal	**14,253.00**
Waste Water	Distribution Lines	NA	3,184.77
	Facilities	876	64,759.18
	Pipelines	0	0.00
		Subtotal	**67,943.95**
Natural Gas	Distribution Lines	NA	2,123.18
	Facilities	62	75.01
	Pipelines	0	0.00
		Subtotal	**2,198.20**
Oil Systems	Facilities	39	4.33
	Pipelines	0	0.00
		Subtotal	**4.33**
Electrical Power	Facilities	153	18,681.30
		Subtotal	**18,681.30**
Communication	Facilities	518	57.50
		Subtotal	**57.50**
		Total	**103,138.27**

3. Hazard Characterization

This chapter describes the scenario earthquake and the development of user-supplied ground motion maps that were used throughout this loss estimation study.

3.1 Scenario Earthquake

The scenario earthquake used for every section of this report was a magnitude 7.7 event and was located at 37.0597° N Latitude and 89.1212° W Longitude. The top of the strike-slip rupture is at a depth of 5 km and the bottom of the rupture is at a depth of 15 km on the northeast fault segment (Cramer, 2006). The scenario earthquake depth was taken to be the average of the top and bottom of rupture (i.e., 10 km).

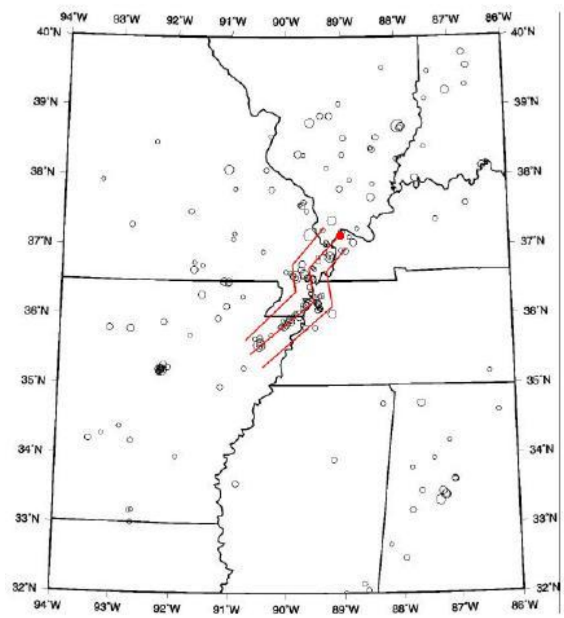


Figure 7: Scenario Earthquake Location

This scenario event location corresponds with the dot at the northern tip of the central theoretical fault in Figure 7. This location was chosen because it is the closest location to the southern tip of Illinois on the theoretical faults; therefore is the likely to cause the most damage in the study region.

3.2 Ground Motion Calculated by HAZUS

HAZUS automatically cuts off the ground motion parameters (PGA, PGV, S_a at 0.3 second, and S_a at 1.0 second) to zero in all census tracts that are farther than 200 km from the earthquake epicenter in any deterministic scenario event. Figure 8 illustrates the ground motion predicted by HAZUS using the scenario earthquake. This cutoff does not follow the true behavior of the attenuation relationships. The tracts with zero ground motion also contained errors in the estimated damage to essential facilities. HAZUS estimated random damage probabilities to essential facilities for those tracts with zero ground motion. Figure 8 illustrates the random damage pattern to essential facilities (police stations) in the census tracts with zero ground motion. The same random damage pattern occurred for all other types of essential facilities.

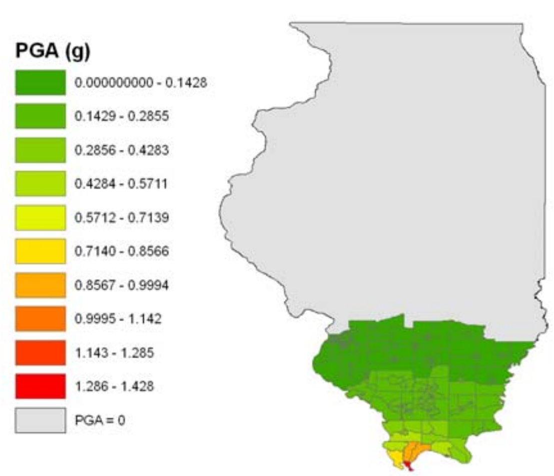


Figure 8: Ground Motion (PGA) Estimated by HAZUS

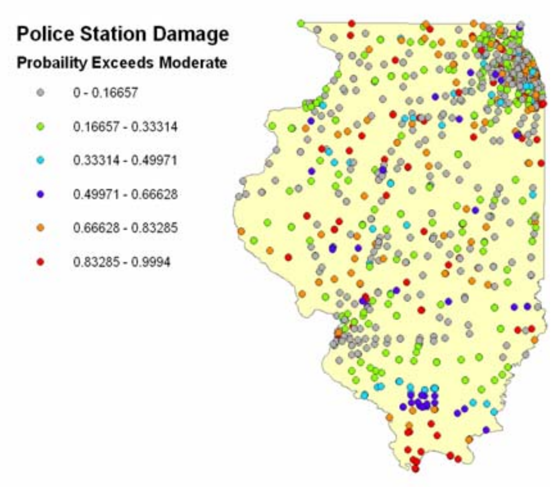


Figure 9: Essential Facility (Police Station) Damage Estimated by HAZUS Using Ground Motion Estimated by HAZUS

3.3 Development of User-Defined Ground Motion Maps

The issues of the 200 km attenuation cutoff and random damage patterns of the essential facilities far from the earthquake epicenter in HAZUS were solved by the development of user-defined ground motion maps. The peak ground acceleration (PGA) resulting from the user-defined ground motion maps is shown in Figure 10, and the resulting damage to police stations is shown in Figure 11. Note that the ground motion is greater than zero for the entire State of Illinois and that the damage to police stations is no longer random. The damage prediction was corrected and follows the hazard. The development of the user-defined ground motion maps is described in the following section of this report.

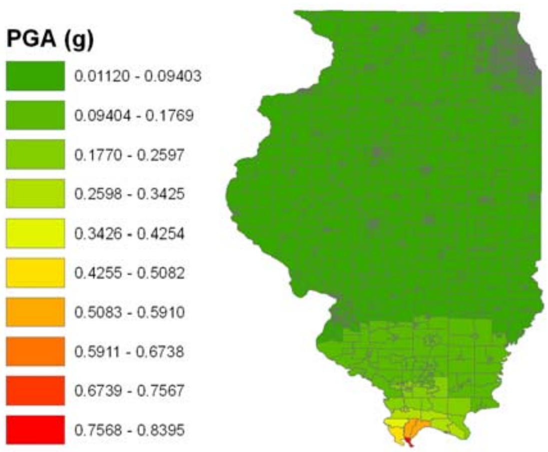


Figure 10: Ground Motion (PGA) using User-Supplied Ground Motion Maps

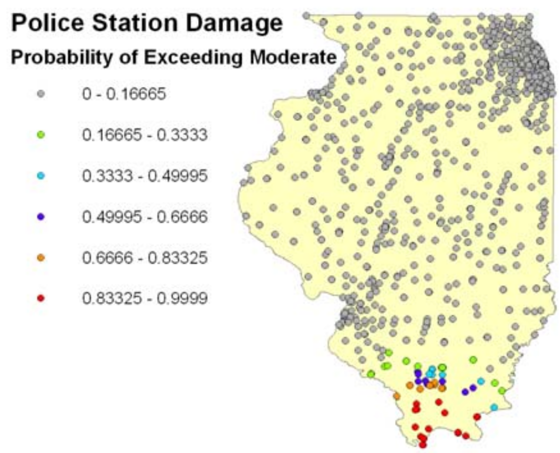


Figure 11: Essential Facility (Police Station) Damage using Ground Motion from User-Defined Ground Motion Maps

A program was developed to create user-defined ground motion maps using the program MATLAB. The inputs to the program were the census tract number, the distance from the earthquake to the centroid of the census tract, and the site class. The ground motion program was used to calculate the ground motion for the centroid of each census tract in Illinois. The ground motion at the centroid was then applied to the entire tract and made into a map usable by HAZUS using ArcGIS.

3.3.1.1 Attenuation Relationships

The CEUS Event attenuation relationship, as described in the Chapter 4 of the HAZUS Technical Manual was used (FEMA, 2006b). The attenuation relationship is a weighted average of four individual relationships, as shown in Table 4.

Table 4: CEUS Event Attenuation Relationships from HAZUS

CEUS Event	
Atkinson and Boore (1997)	0.286
Toro, Abrahamson and Schneider (1997)	0.286
Frankel, Mueller, Barnhard, Perkins et al. (1996)	0.286
Campbell (2002)	0.142

The resulting ground motions for each individual attenuation relationship in Table 4 were compared with the ground motions produced by the same individual relationships in the HAZUS loss estimation tool. The predicted ground motions from the program showed reasonable comparison with those from HAZUS, aside from the 200 km cutoff used in HAZUS. The individual attenuation comparisons are not presented in this report.

The predicted ground motion for the combined CEUS Event attenuation relationship using the ground motion program was also compared to the ground motions predicted by HAZUS. The comparison between the program and HAZUS for PGA, PGV, S_a at short periods, and S_a at 1.0 second periods are shown in Figure 12, Figure 13, Figure 14, and Figure 15, respectively. Note that unlike the HAZUS ground motions, the user-defined motions do not drop to zero at the distance 200 km.

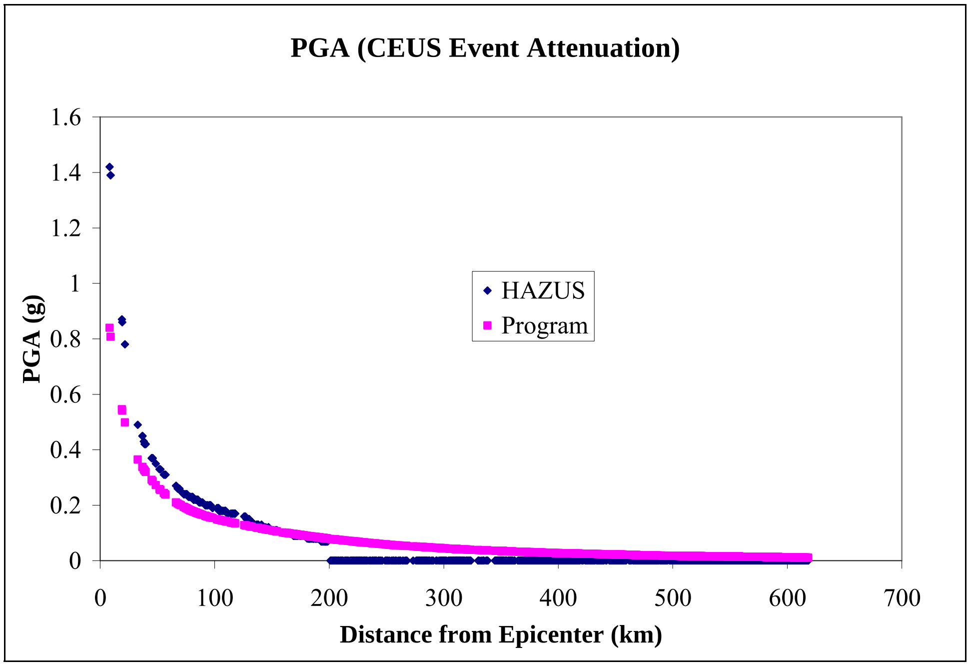


Figure 12: PGA for HAZUS vs. Ground Motion Program

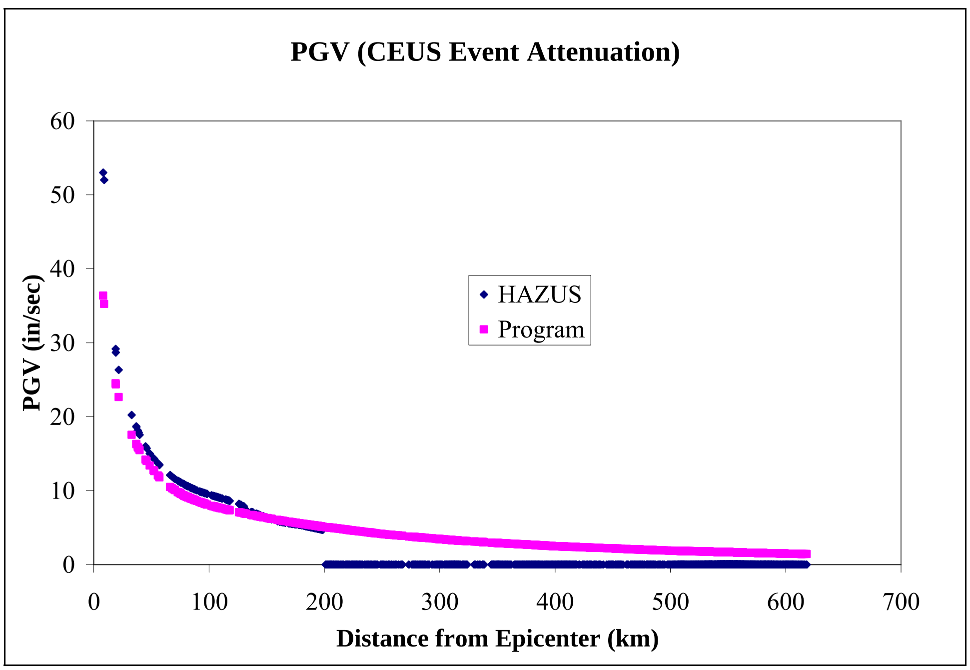


Figure 13: PGV for HAZUS vs. Ground Motion Program

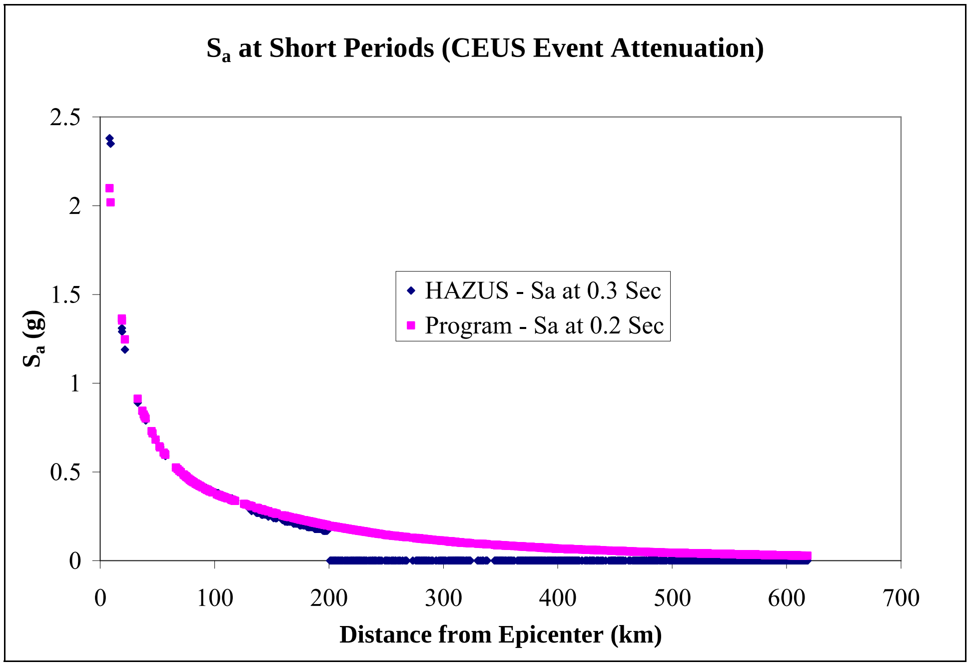


Figure 14: S_a at 0.3 Second for HAZUS vs. Ground Motion Program

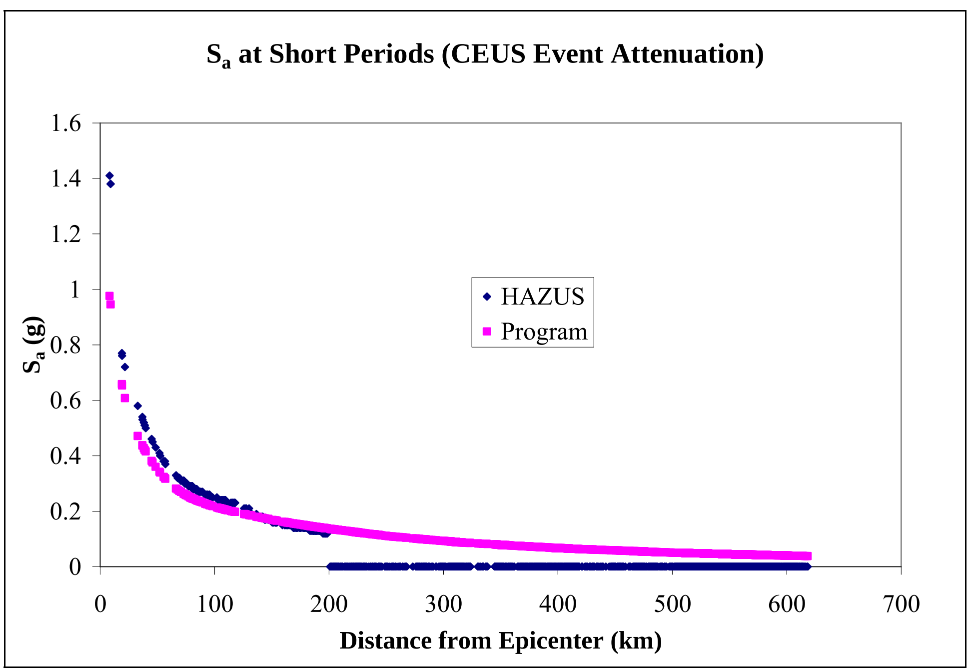


Figure 15: S_a at 1.0 Second for HAZUS vs. Ground Motion Program

The short period spectral acceleration ground motion parameters for a period of 0.3 second in HAZUS and for a period of 0.2 seconds in the ground motion program. This difference is due to the fact that HAZUS uses the spectral acceleration at 0.3 second for short period response; however, the spectral acceleration at 0.2 second is readily available in the attenuation relationships that were used to develop the ground motion program. The response spectrum is flat between 0.3 and 0.2 seconds, as shown by the horizontal portion of the response spectrum in Figure 16. Therefore, taking the spectral acceleration at a period of either 0.2 or 0.3 second yielded equivalent results. The spectral acceleration at 0.2 seconds were used throughout this study.

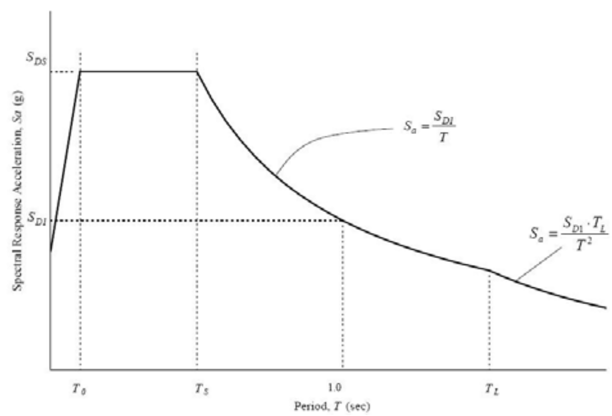


Figure 16: Ground Motion Response Spectrum (FEMA, 2003)

3.3.1.2 Effects of Soil Site Condition

A site class map was provided for the southern one-third of Illinois by the Illinois State Geological Survey (ISGS) (Bauer, 2006). The map specifies site classes A, B, C, D, E, and F. All areas assigned to site class F were reassigned to site class E because HAZUS only uses site class A through E to modify ground motions. The resulting site class map is shown in Figure 17. The development of the site class map is discussed in Chapter 5 of this report.

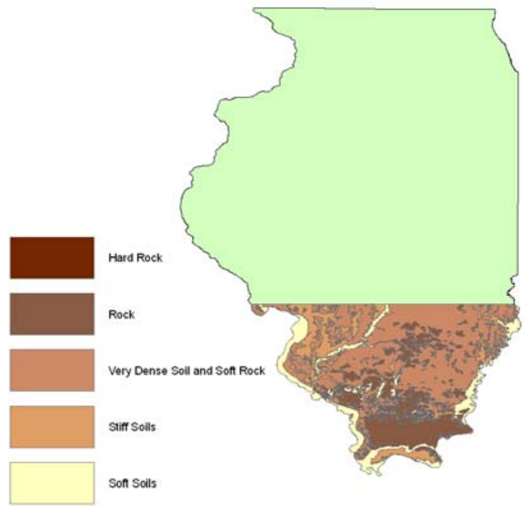


Figure 17: Site Class Map Provided by ISGS

The user-defined ground motion program modifies the ground motions calculated by the attenuation relationships using the NEHRP site class factors for each site class. The NEHRP site class factors were used to modify the ground motions according to the following equations. The procedure is a slightly modified version of that described in Chapter 3 of the NEHRP Provisions (FEMA, 2003).

$$S_{aS,i} = S_{aS,B} F_a$$

$$S_{a1,i} = S_{a1,B} F_v$$

$PGA_i = 0.6 \dfrac{S_{aS,i}}{T_0} T + 0.4 S_{aS,i}$ is taken as $PGA_i = 0.4 S_{aS,i}$ at $T = 0$ seconds.

$$PGV = \left(\frac{386.4}{2\pi} S_{a1} \right) / 1.65$$

where:

$S_{aS,i}$ = spectral acceleration at short periods at site class i

$S_{aS,B}$ = spectral acceleration at short periods at site class B, given by attenuation relationships

$S_{a1,i}$ = spectral acceleration at 1.0 second periods at site class i

$S_{a1,B}$ = spectral acceleration at 1.0 second periods for at class B, given by attenuation relationships

F_a = short period site coefficient (NEHRP section 3.3.2)

F_v = long period site coefficient (NEHRP section 3.3.2)

PGA_i = peak ground acceleration at site class i

3.4 Consideration of Liquefaction Effects

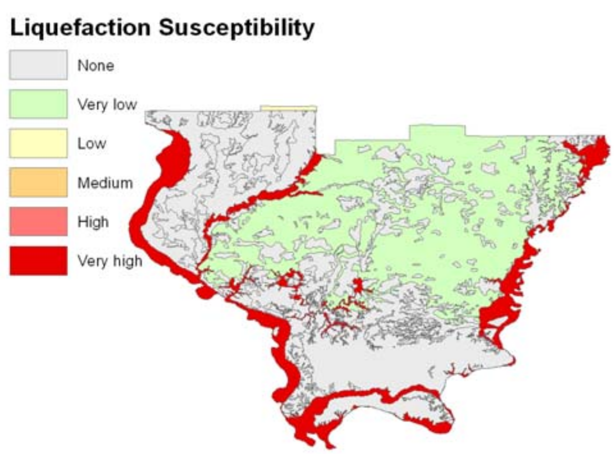


Figure 18: Liquefaction Susceptibility Map

Liquefaction maps input into HAZUS specify the liquefaction susceptibly for the study region. Liquefaction was not included in the ground motion program described in the previous sections. The liquefaction susceptibility map used in this study is shown in Figure 18 (FEMA, 2006c). The liquefaction susceptibility indices, with increasing susceptibility to liquefaction, are “none”, “very low”, “low”, “moderate”, “high”, and “very high”. HAZUS estimates permanent ground displacement using the liquefaction susceptibility index and the peak ground acceleration in each census tract. The procedure is outlined in Chapter 4 of the HAZUS Technical Manual.

The liquefaction calculations described in the HAZUS Technical Manual were followed for a set of census tracts, and it was determined that the permanent ground displacement due to liquefaction is calculated correctly by HAZUS for all liquefaction susceptibility indices except “very low”. For this index, HAZUS incorrectly estimates a permanent ground displacement of zero for any PGA value. To remedy this issue, all census tracts with a liquefaction susceptibility index of “very low” were assigned an index of “low”. This slightly increased the liquefaction results in the affected tracts.

4. HAZUS Level 1 Analysis and Results

A HAZUS level 1 analysis was completed using all default inventories and loss parameters; however the ground motion was improved and user-defined. The analysis and results are described in the following sections.

4.1 Seismic Hazard

The user-defined ground motion was calculated using the method described in the Hazard Definition Chapter of this report. The soil was assumed to be of uniform site class D throughout the entire study region. This uniform soil condition is consistent with what HAZUS assumes for soils in a default analysis. The maximum calculated values of PGA, PGV, S_a at 0.2 second, and S_a at 1.0 second in the study region are 0.8395 g, 36.3875 inches/second, 2.0988 g, and 0.9763g, respectively. The ground motion maps are shown in the figures below. Figures 19 and 20 show maps of PGA and PGV, respectively.

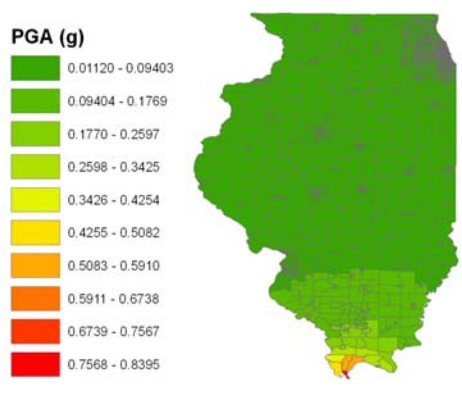


Figure 19: PGA from User-Supplied Ground Motion Maps

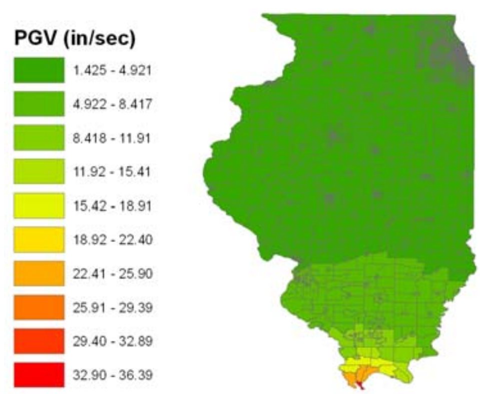


Figure 20: PGV from User-Supplied Ground Motion Maps

Figures 21 and 22 show maps of S_a at a short period and 1.0 second period, respectively.

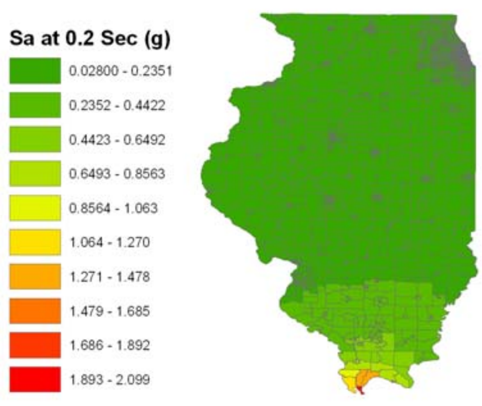


Figure 21: Sa at 0.2 Second from User-Supplied Ground Motion Maps

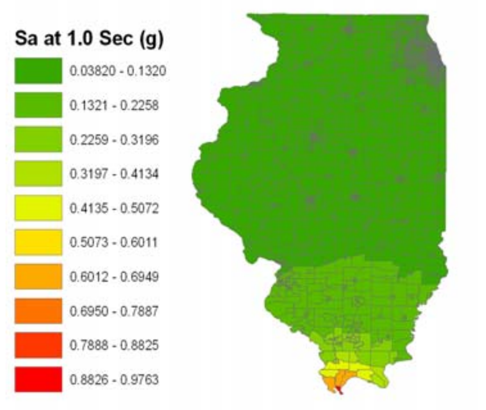


Figure 22: Sa at 1.0 Second from User-Supplied Ground Motion Maps

4.2 Damage Estimates

The damage estimated by HAZUS for the analysis with default inventories and parameters with user-supplied ground motion are described in the following sections.

4.2.1 General Building Stock

HAZUS estimates that about 51,537 buildings in the general building stock will be at least moderately damaged. This estimate is over 2% of the total number of buildings in the region. HAZUS estimated that 2,854 buildings in the State of Illinois that will be damaged beyond repair. The estimated probabilities of reaching or exceeding the damage states of None, Slight, Moderate, Extensive, and Complete for each occupancy class in the HAZUS general building stock are given in Table 5.

Table 5: Expected Building Damage by Occupancy

	None		Slight		Moderate		Extensive		Complete	
	Count	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**
Agriculture	431	0.01	19	0.03	13	0.03	4	0.04	2	0.06
Commercial	40,504	1.29	676	1.18	510	1.39	174	1.45	37	1.29
Education	341	0.01	6	0.01	6	0.02	2	0.02	1	0.03
Government	1,367	0.04	44	0.08	36	0.10	12	0.10	5	0.17
Industrial	7,318	0.23	70	0.12	59	0.16	19	0.16	3	0.11
Other	368,538	11.73	16,501	28.92	21,785	59.43	8,100	67.33	1,544	54.08
Religion	2,120	0.07	51	0.09	39	0.11	16	0.13	5	0.18
Single Family	2,722,002	86.62	39,689	69.56	14,206	38.76	3,702	30.77	1,258	44.08
Total	**3,142,619**		**57,056**		**36,654**		**12,030**		**2,854**	

The estimated probabilities of reaching or exceeding the damage states for each general building type are given in Table 6.

Table 6: Expected Building Damage by Building Type (All Design Levels)

	None		Slight		Moderate		Extensive		Complete	
	Count	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**
Wood	2,322,418	73.90	24354	42.68	5,919	16.15	733	6.10	61	2.15
Steel	16,327	0.52	263	0.46	327	0.89	129	1.07	26	0.90
Concrete	31,102	0.99	832	1.46	738	2.01	239	1.99	34	1.18
Precast	5,450	0.17	71	0.12	91	0.25	47	0.39	8	0.29
RM	5,806	0.18	29	0.05	41	0.11	19	0.15	2	0.05
URM	660,813	21.03	16403	28.75	8,318	22.69	2,948	24.51	1,226	42.94
MH	100,703	3.20	15104	26.47	21,220	57.89	7,914	65.79	1,498	52.49
Total	**3,142,619**		**57,056**		**36,654**		**12,030**		**2,854**	

4.2.2 Emergency Response and Essential Facilities

The estimated damage and functionality for the default HAZUS inventory of essential facilities in the State of Illinois is summarized in Table 7. The loss estimates for the individual types of essential facilities (i.e., medical facilities, schools, emergency centers, police stations, and fire stations) are described in the following sections.

Table 7: Expected Damage to Essential Facilities

Classification	Total # of Facilities	At Least Moderate Damage		Complete Damate		With Functionality > 50% on day 1	
		Count	%	Count	%	Count	%
Hospitals	227	16	7.0	1	0.4	206	90.7
Schools	5,283	91	1.7	9	0.2	5,127	97.0
EOCs	149	5	3.4	2	1.3	143	96.0
PoliceStations	866	36	4.2	6	0.7	805	93.0
FireStations	1,007	37	3.7	7	0.7	938	93.1

4.2.2.1 Medical Facilities

HAZUS estimated that of the 227 hospitals in the State of Illinois, 16 would suffer at least moderate damage, and 21 of these hospitals would be less than 50% functional on the day of the earthquake. Figure 23 shows the probability of exceeding moderate structural damage and Figure 24 shows the estimated functionality for all medical facilities in Illinois. The majority of damage and loss of functionality occur in the southern portion of the state.

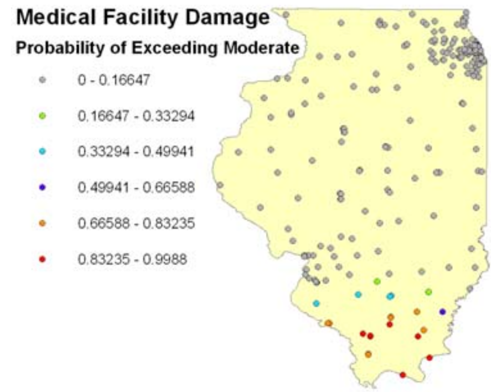


Figure 23: Medical Facility Damage Probability of Exceeding Moderate Damage

Of the estimated 42,983 hospital beds available for use in the State of Illinois, HAZUS estimates that about 80.5% of the total beds will be available for patients already in the hospitals and new patients that were injured by the earthquake on the day of the earthquake. After one week, 86% of the beds were estimated to be back in service. By 30 days after the event, 95% of the beds will be available. Table 2 shows the number of beds available in Illinois at different time periods following the earthquake.

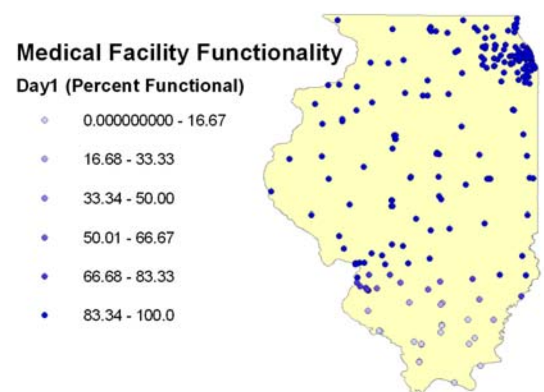


Figure 24: Medical Facility Functionality at Day 1

Table 8: Expected Number of Hospital Beds Available in Illinois

Number of Beds Available									
At Day 1		At day 3		At day 7		At day 30		At day 90	
# of Beds	%	# of Beds	%	# of Beds	%	# of Beds	%	# of Beds	%
34,597	80.5	34,650	80.6	37,015	86.1	40,763	94.8	41,680	97

Figure 25 shows a plot of hospital bed recovery for the day of the earthquake, 3 days, 7 days, 30 days, and 90 days after the earthquake.

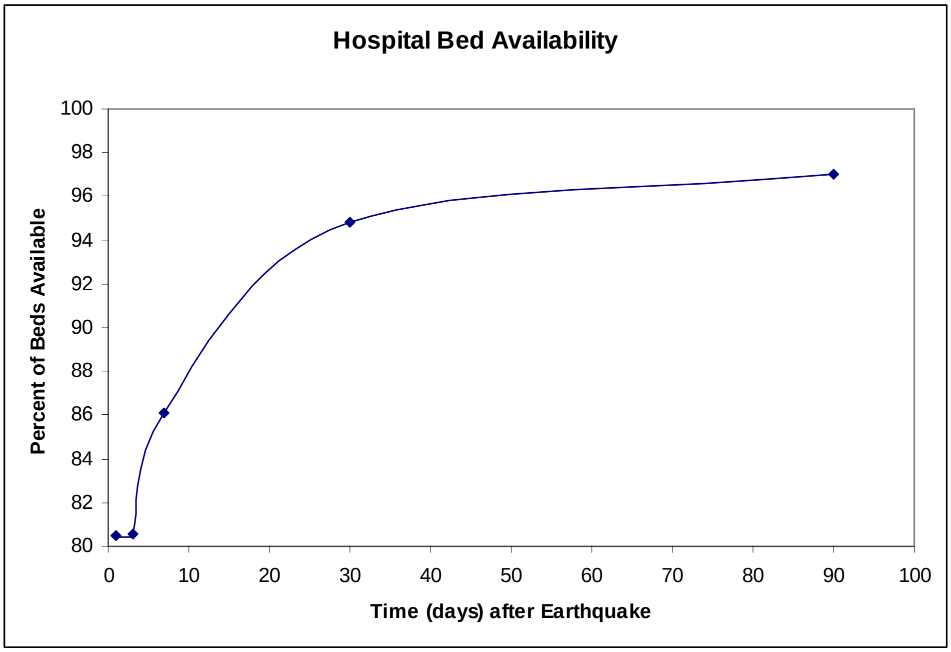


Figure 25: Hospital Bed Availability Plot

4.4.2.2 Schools

HAZUS estimated that of the approximately 5,300 schools in the State of Illinois, 91 would suffer at least moderate damage, and about 160 of these schools would be less than 50% functional on the day of the earthquake. Figure 26 shows the probability of exceeding moderate structural damage for schools in the State of Illinois. Table 9 tabulates the functionality of schools on the day of the earthquake. The majority of schools in northern Illinois were estimated to be

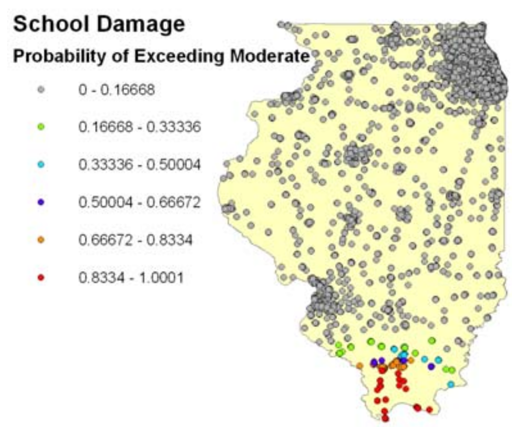


Figure 26: School Damage Probability of Exceeding Moderate Damage

completely (100%) functional on the day of the earthquake because the ground motion is relatively small in the northern part of the state.

Table 9 : Functionality of Schools at Day1

Functionality of Schools at Day 1		
Percent Functional	**Count**	**Percent of Total**
0 - 20%	99	1.9
20% - 40%	36	0.7
40% - 60%	62	1.2
60% - 80%	242	4.6
80% - 100%	4844	91.7

Figure 27 illustrates the restoration of school functionality. The percent of the total number of schools with a functionality of at least 50% on the day of the earthquake, 3 days, 7 days, 14 days, 30 days, and 90 days after the earthquake are plotted.

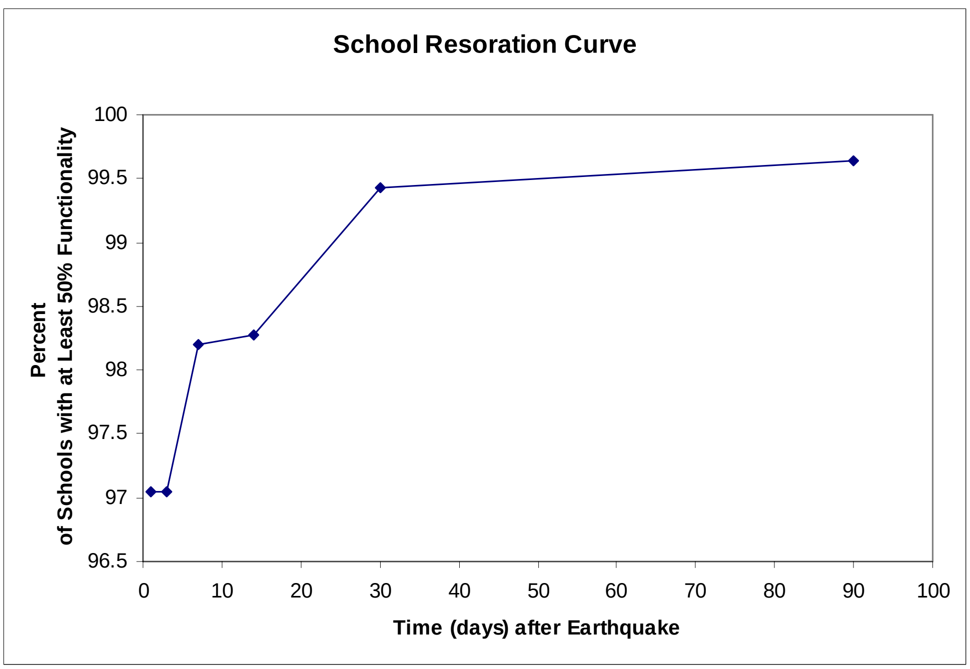


Figure 27: School Restoration Curve

4.2.2.3 Police Stations

HAZUS estimated that of the approximately 870 police stations in the State of Illinois, 36 would suffer at least moderate damage. About 60 of these police stations would be less than 50% functional on the day of the earthquake. Figure 28 shows the probability of exceeding moderate structural damage for police stations in the study region. Table 10 tabulates the functionality of police stations on the day of the earthquake. Once again, nearly all of the police stations in northern Illinois are estimated to be fully functional on the day of the earthquake due to the small ground motions in the north.

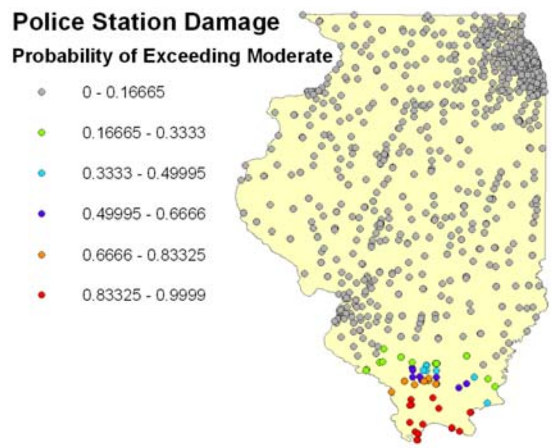


Figure 28: Police Station Damage Probability of Exceeding Moderate Damage

Table 10: Functionality of Police Stations at Day 1

Functionality of Police Stations at Day 1		
Percent Functional	**Count**	**Percent of Total**
0 - 20%	38	4.4
20% - 40%	14	1.6
40% - 60%	18	2.1
60% - 80%	53	6.1
80% - 100%	743	85.8

Figure 29 illustrates the restoration of police station functionality. The percent of the total number of police stations with a functionality of at least 50% on the day of the earthquake, 3 days, 7 days, 14 days, 30 days, and 90 days after the earthquake are plotted.

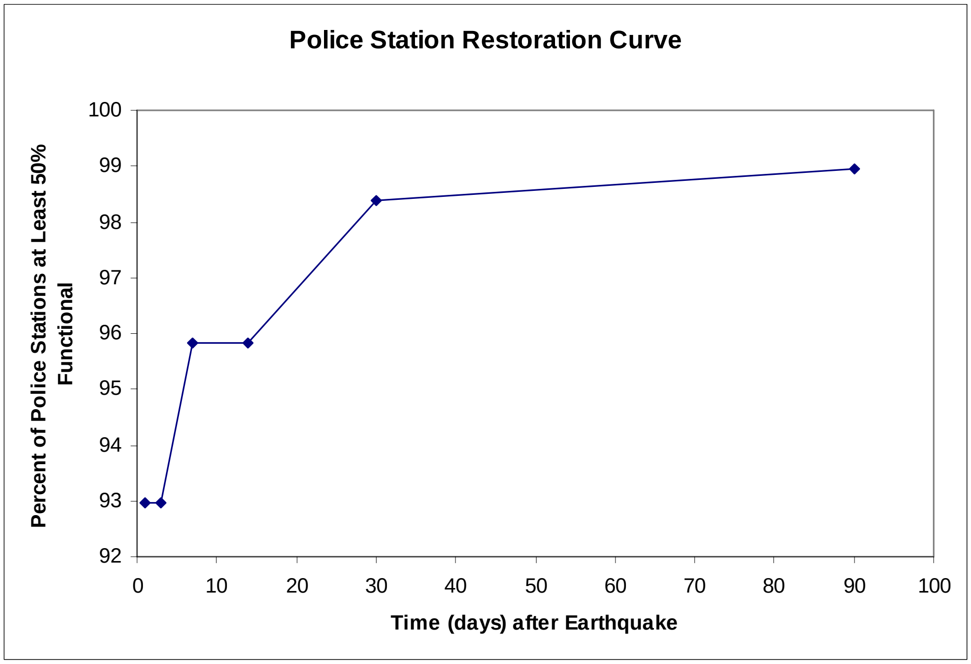


Figure 29: Police Station Restoration Curve

4.2.2.4 Fire Stations

HAZUS estimated that of the approximately 1,007 fire stations in the State of Illinois, 37 would suffer at least moderate damage, and about 70 of these fire stations would be less than 50% functional on the day of the earthquake. Figure 30 shows the probability of exceeding moderate structural damage for fire stations in the State of Illinois. Table 11 tabulates the functionality of fire stations on the day of the earthquake. The fire stations that are by far the most likely to suffer damage and reduced functionality are those in the southern counties of the state because of their location relative to the earthquake epicenter.

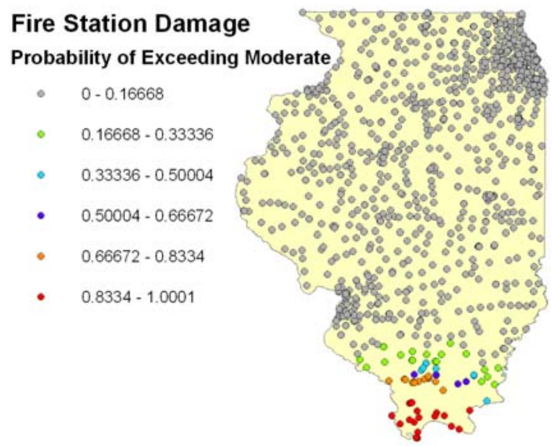


Figure 30: Fire Station Damage Probability of Exceeding Moderate Damage

Table 11: Functionality of Fire Stations at Day 1

Functionality of Fire Stations at Day 1		
Percent Functional	**Count**	**Percent of Total**
0 - 20%	40	4.0
20% - 40%	19	1.9
40% - 60%	21	2.1
60% - 80%	68	6.8
80% - 100%	859	85.3

Figure 31 illustrates the restoration of fire station functionality. The percent of the total number of fire stations with a functionality of at least 50% on the day of the earthquake, 3 days, 7 days, 14 days, 30 days, and 90 days after the earthquake are plotted.

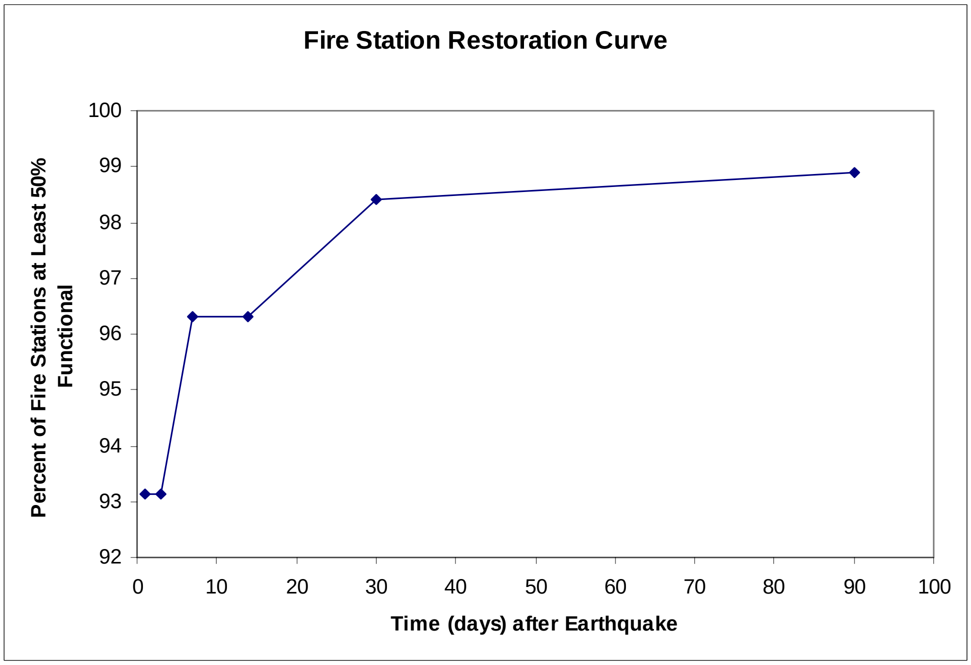


Figure 31: Fire Station Restoration Curve

4.2.2.5 Emergency Centers

HAZUS estimated that of the 149 emergency centers in the State of Illinois, 5 would suffer at least moderate damage, and about 6 of these fire stations would be less than 50% functional on the day of the earthquake. Figure 32 shows the probability of exceeding moderate structural damage for fire stations in the State of Illinois. Table 12 tabulates the functionality of emergency centers on the day of the earthquake. About three percent of the emergency centers in Illinois are expected to have significant damage, and about ten percent of the centers are expected to have significantly reduced functionality on the day of the earthquake.

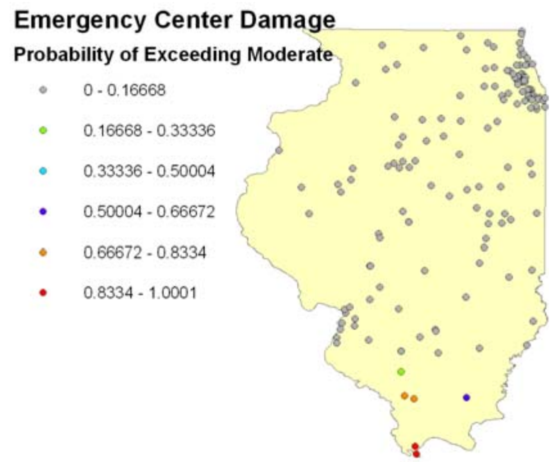


Figure 32: Emergency Center Damage Probability of Exceeding Moderate Damage

Table 12: Functionality of Emergency Centers at Day 1

Functionality of Emergency Operation Centers at Day 1		
Percent Functional	**Count**	**Percent of Total**
0 - 20%	5	3.4
20% - 40%	1	0.7
40% - 60%	1	0.7
60% - 80%	10	6.8
80% - 100%	130	88.4

Figure 33 illustrates the restoration of emergency center functionality. The percent of the total number of emergency centers with a functionality of at least 50% on the day of the earthquake, 3 days, 7 days, 14 days, 30 days, and 90 days after the earthquake are plotted.

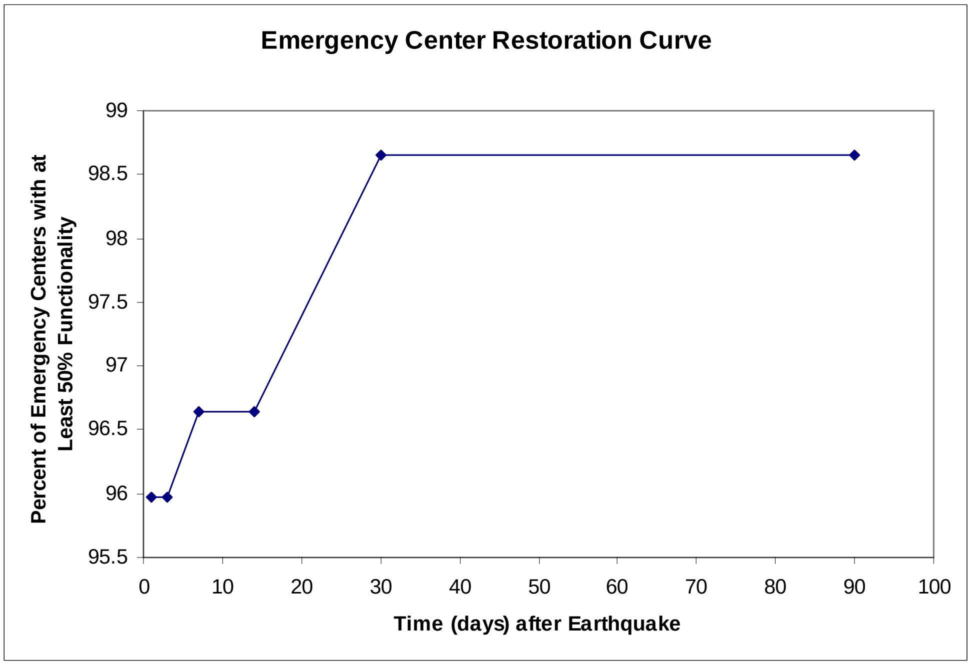


Figure 33: Emergency Centers Restoration Curve

4.2.3 Utility Systems

The utility system facility damage, as estimated by HAZUS is summarized in Table 13. A relatively small number of utility system facilities—less than five percent of any utility inventory—suffer at least moderate structural damage, and no facilities are damaged beyond repair. Nearly all of the utility system facilities are expected to be at least 50% functional one week after the earthquake.

Table 13: Expected Utility System Facility Damage

System	Total # of Facilities	At Least Moderate Count	At Least Moderate %	Complete Damate Count	Complete Damate %	with Functionality > 50 % After Day 1 Count	After Day 1 %	After Day 7 Count	After Day 7 %
Potable Water	242	5	2.1	0	0.0	236	97.5	242	100.0
Waste Water	876	17	1.9	0	0.0	847	96.7	874	99.8
Natural Gas	62	3	4.8	0	0.0	59	95.2	62	100.0
Oil Systems	39	0	0.0	0	0.0	39	100.0	39	100.0
Electrical Power	153	2	1.3	0	0.0	151	98.7	153	100.0
Communication	518	6	1.2	0	0.0	517	99.8	518	100.0

Table 14 shows the total pipeline length, number of pipeline leaks, and number of pipeline breaks for the potable water, waste water, natural gas, and oil utility systems. Note that the HAZUS default inventory contains no oil pipelines, therefore no damage is estimated for that utility system in a HAZUS level 1 analysis.

Table 14: Expected Utility System Pipeline Damage

System	Total Pipelines Length (kms)	Number of Leaks	Number of Breaks
Potable Water	265,398	7825	1956
Waste Water	159,239	6189	1547
Natural Gas	106,159	6616	1654
Oil	0	0	0

The estimated performance of the potable water and electric power utility systems at various intervals after the earthquake is summarized in Table 15. The performance of the water and electric systems are quantified by the number of households without service. Less than 1% of the total households in Illinois are expected to be without potable water, and less than 1% of the households in the State are expected to be without electric power on the day of the earthquake. The majority of repairs to the water and electric utility system are estimated to be completed within one week of the earthquake. These estimates are based on restoration curves within HAZUS.

Table 15: Expected Potable Water and Electric Power System Performance

		At Day 1		At Day 3		At Day 7		At Day 30		At Day 90	
	Total # of Households	# of Facilities	% of Total	# of Facilities	% of Total	# of Facilities	% of Total	# of Facilities	% of Total	# of Facilitie	% of Total
Potable Water	4,591,779	13,141	0.29	5,836	0.13	1,761	0.04	0	0.00	0	0.00
Electric Power		10,754	0.23	6,474	0.14	2,540	0.06	496	0.01	15	0.00

4.2.3.1 Potable Water Utility System

In addition to the potable water pipeline damage, the water facility damage was estimated. The probability of exceeding moderate structural damage for each water facility in the study region can be seen in Figure 34, and the functionality of each facility on the day of the earthquake is shown in Figure 35. The loss (repair cost), in thousands of dollars for each facility is shown on the map in Figure 36. The total loss to the potable water facilities is estimated to be $87 million. The estimated loss to the potable water distribution lines was $35 million. This total estimated loss is less than one percent of the total value of the potable water utility system.

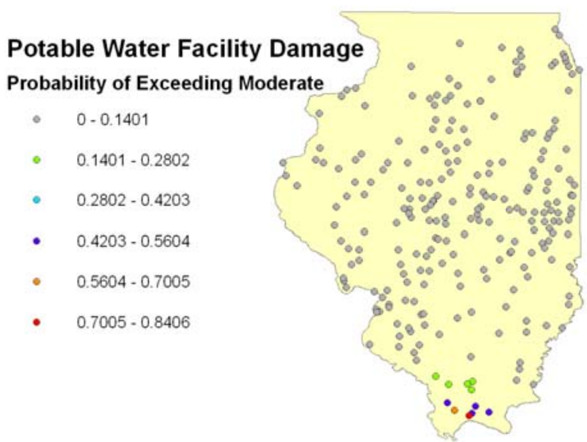


Figure 34: Potable Water Facility Damage Probability of Exceeding Moderate Damage

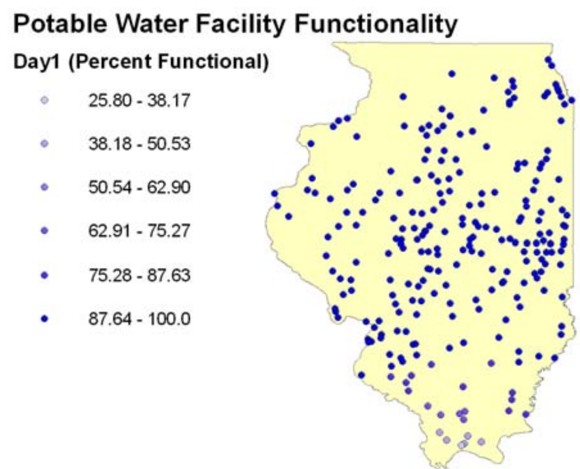


Figure 35: Potable Water Facility Functionality at Day 1

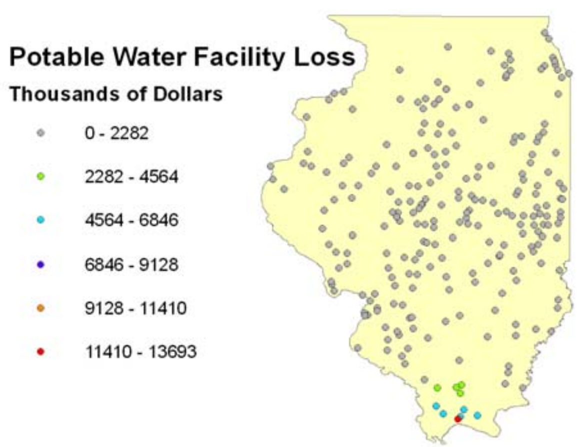


Figure 36: Potable Water Facility Loss

Figure 37 illustrates the restoration of potable water facility functionality. The percent of the total number of potable water facilities with a functionality of at least 50% on the day of the earthquake, 3 days, 7 days, 14 days, 30 days, and 90 days after the earthquake are plotted.

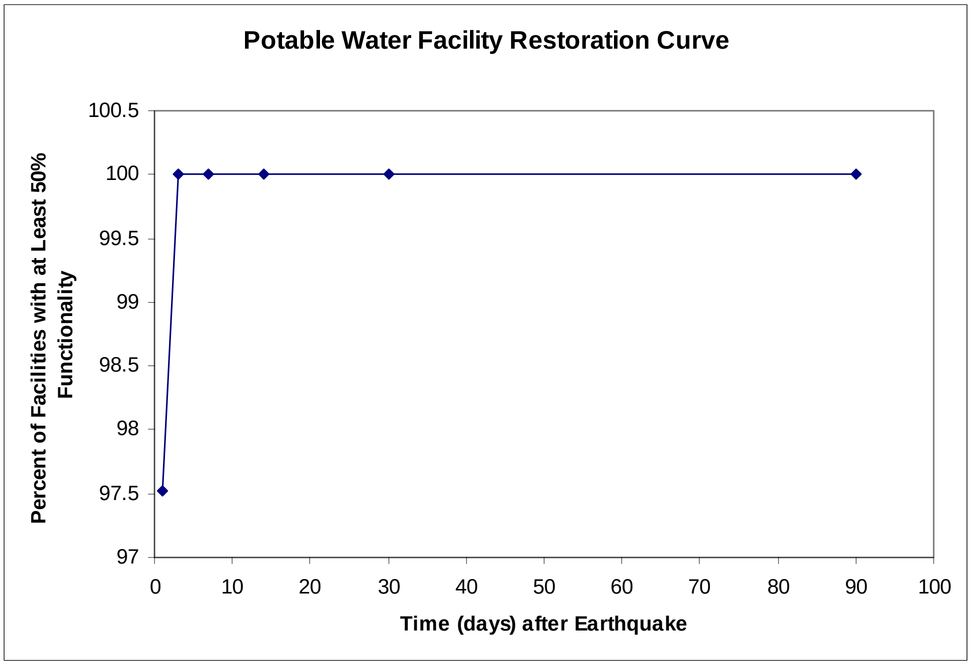


Figure 37: Potable Water Facilities Restoration Curve

4.2.3.2 Wastewater Utility System

The estimated damage to wastewater facilities is illustrated. The probability of exceeding moderate structural damage for each wastewater facility in the study region can be seen in Figure 38, and the functionality of each facility on the day of the earthquake is shown in Figure 39. The loss (repair cost), in thousands of dollars for each facility is shown on the map in Figure 40. The total loss to the wastewater facilities is estimated to be $880 million. The total loss for the wastewater facilities distribution lines was estimated to be $27 million. The total of these losses is approximately 1.3 percent of the total value of the wastewater utility system.

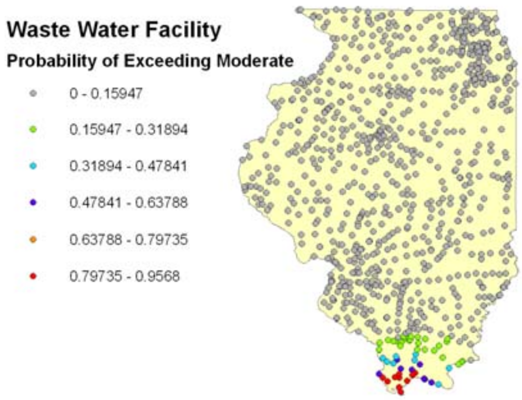


Figure 38: Wastewater Facility Damage Probability of Exceeding Moderate

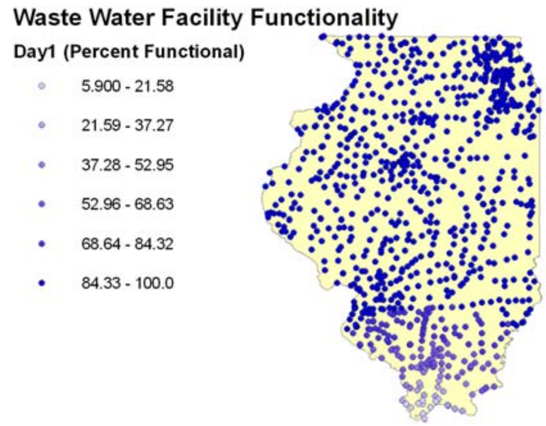


Figure 39: Wastewater Facility Functionality at Day 1

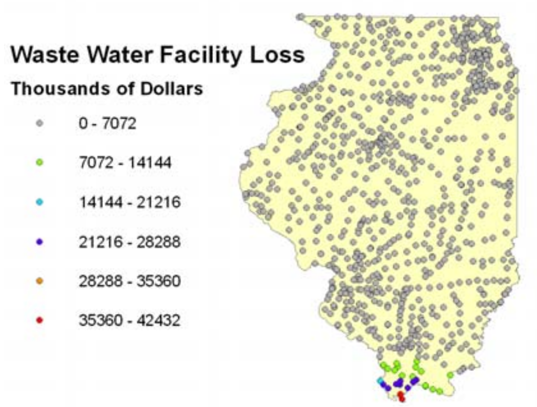


Figure 40: Wastewater Facility Loss

Figure 41 illustrates the restoration of waste water facility functionality. The percent of the total number of waste water facilities with a functionality of at least 50% on the day of the earthquake, 3 days, 7 days, 14 days, 30 days, and 90 days after the earthquake are plotted.

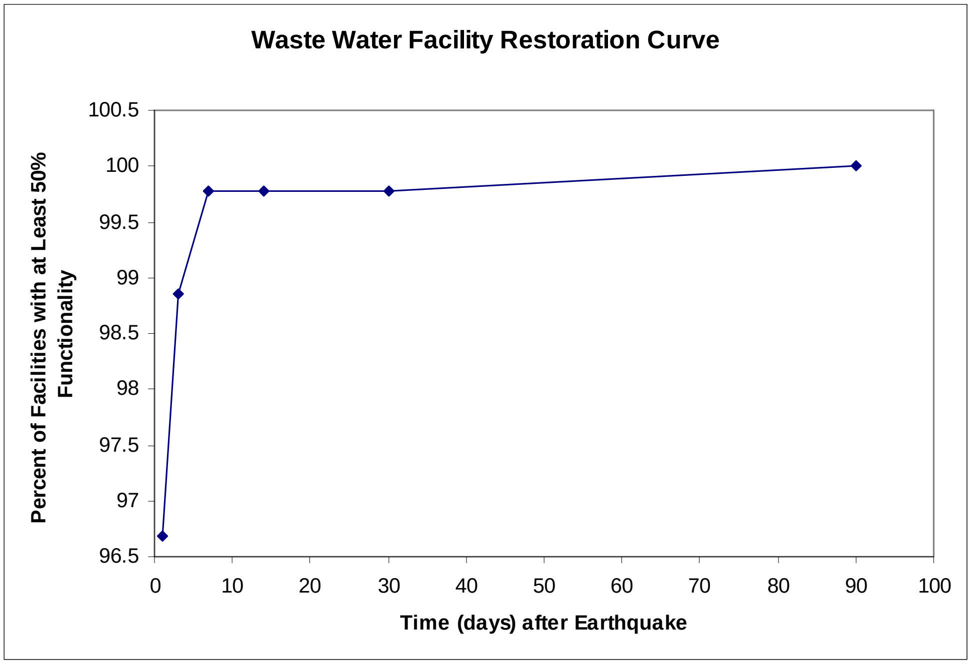


Figure 41: Waste Water Facility Restoration Curve

4.2.3.3 Natural Gas Utility System

The estimated damage to natural gas facilities is shown in the following figures. The probability of exceeding moderate structural damage for each natural gas facility in the study region can be seen in Figure 42, and the functionality of each facility on the day of the earthquake is shown in Figure 43. The loss (repair cost), in thousands of dollars for each facility is shown on the map in Figure 44. The total loss to the natural gas facilities was estimated to be $1 million, and the total loss to the distribution lines was estimated to be $29 million. These loss estimates sum to approximately 1.4 percent of the total value of the natural gas utility system.

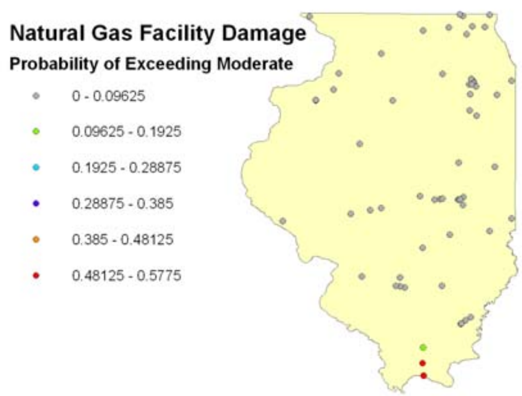


Figure 42: Natural Gas Facility Damage Probability of Exceeding Moderate

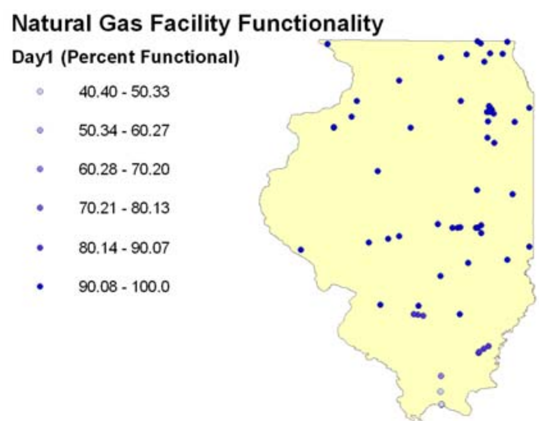


Figure 43: Natural Gas Facility Functionality at Day 1

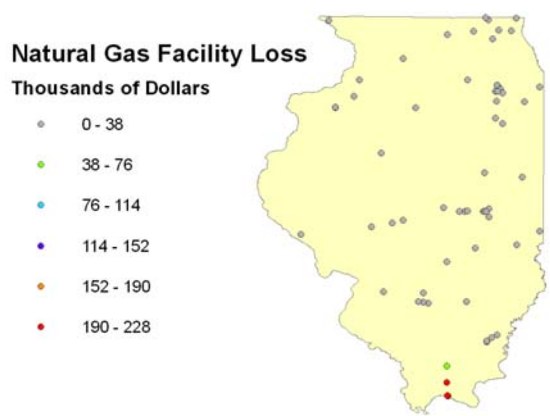


Figure 44: Natural Gas Facility Loss

Figure 45 illustrates the restoration of natural gas facility functionality. The percent of the total number of natural gas facilities with a functionality of at least 50% on the day of the earthquake, 3 days, 7 days, 14 days, 30 days, and 90 days after the earthquake are plotted.

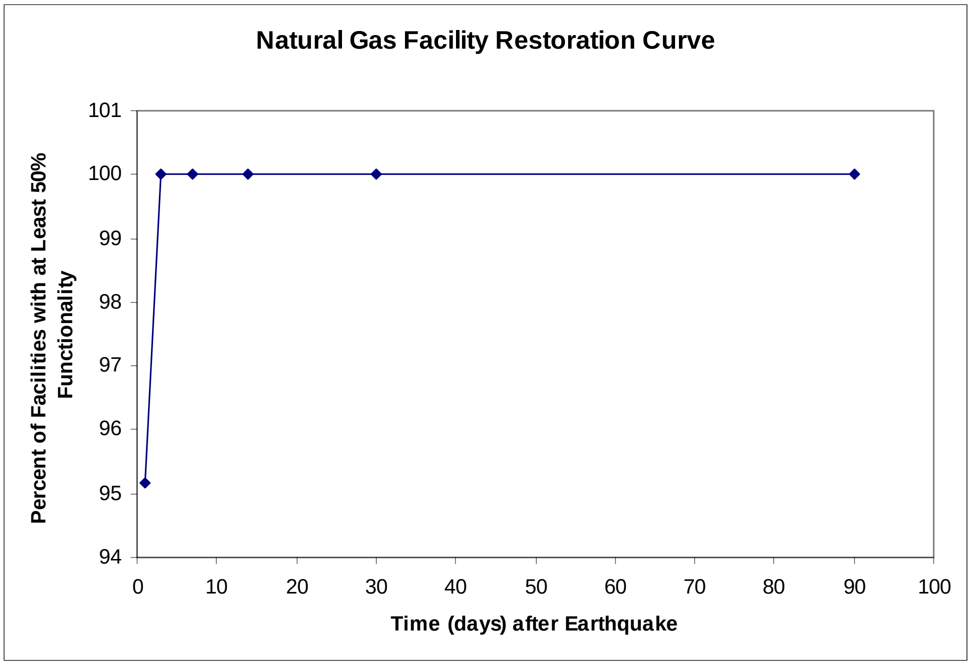


Figure 45: Natural Gas Facility Restoration Curve

4.2.3.4 Electric Power Facilities

The estimated damage to electrical power facilities is shown in the following figures. The probability of exceeding moderate structural damage for each natural gas facility in the study region can be seen in Figure 46, and the functionality of each facility on the day of the earthquake is shown in Figure 47. The loss (repair cost), in thousands of dollars for each facility is shown on the map in Figure 48. The total loss to the electrical power facilities is estimated to be $101 million. The damage to electric power lines are not estimated by HAZUS.

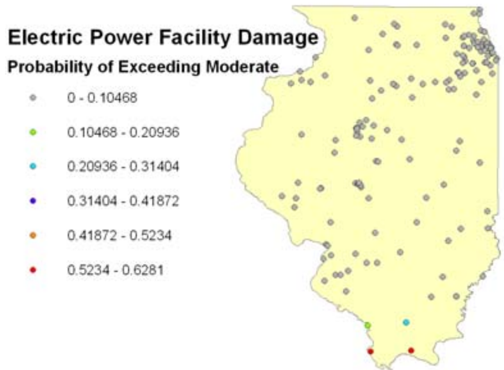


Figure 46: Electric Power Facility Damage Probability of Exceeding Moderate

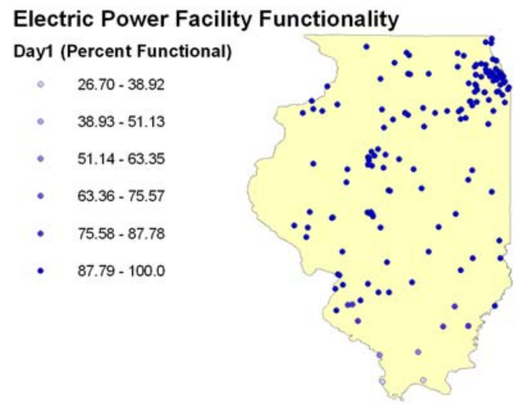


Figure 47: Electric Power Facility Functionality at Day1

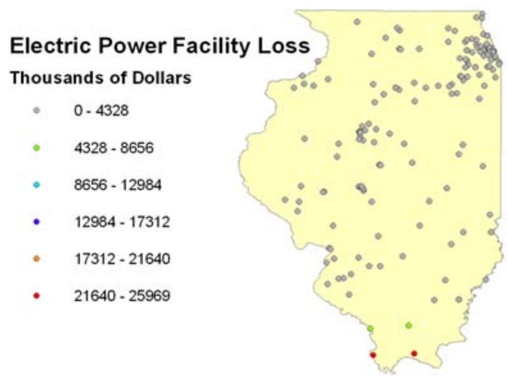


Figure 48: Electric Power Facility Loss

Figure 49 illustrates the restoration of electric power facility functionality. The percent of the total number of electric power facilities with a functionality of at least 50% on the day of the earthquake, 3 days, 7 days, 14 days, 30 days, and 90 days after the earthquake are plotted.

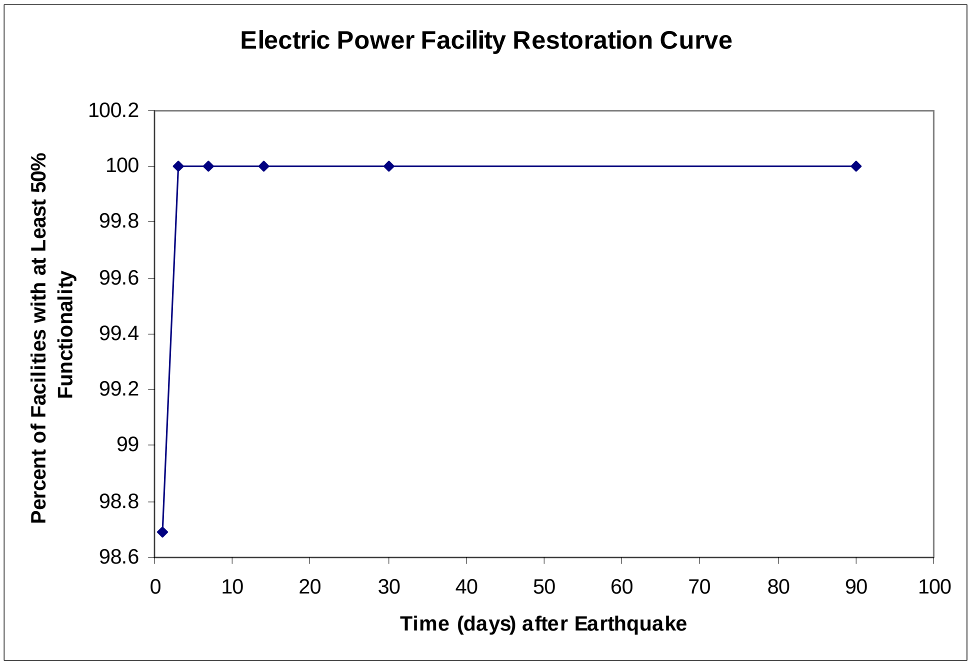


Figure 49: Electric Power Facility Restoration Curve

4.2.3.5 Communication Networks

The estimated damage to the communication network facilities is shown in Figures 50 through 52. The probability of exceeding moderate structural damage for each communication facility in the study region can be seen in Figure 50, and the functionality of each facility on the day of the earthquake is shown in Figure 51. The loss (repair cost), in thousands of dollars for each facility is shown on the map in Figure 52. The total loss to the communication network facilities is estimated to be $0.5 million. The damage to the communication lines is not estimated by HAZUS.

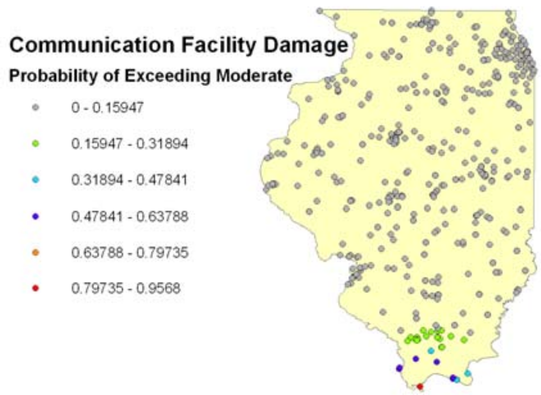


Figure 50: Communication Facility Damage Probability of Exceeding Moderate

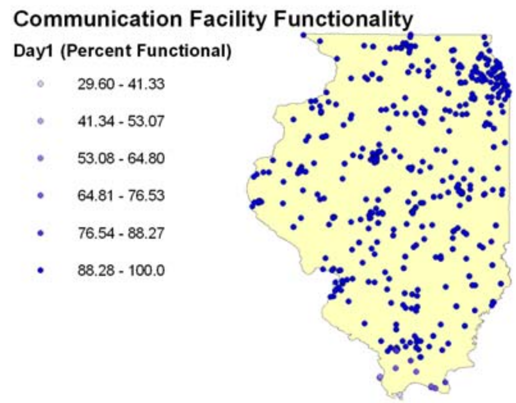


Figure 51: Communication Facility Functionality at Day 1

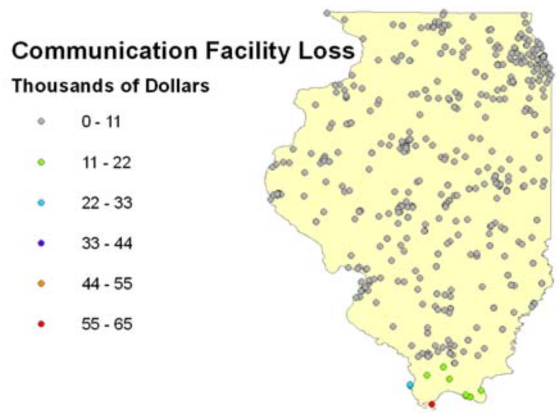


Figure 52: Communication Facility Loss

Figure 53 illustrates the restoration of communication facility functionality. The percent of the total number of communication facilities with a functionality of at least 50% on the day of the earthquake, 3 days, 7 days, 14 days, 30 days, and 90 days after the earthquake are plotted.

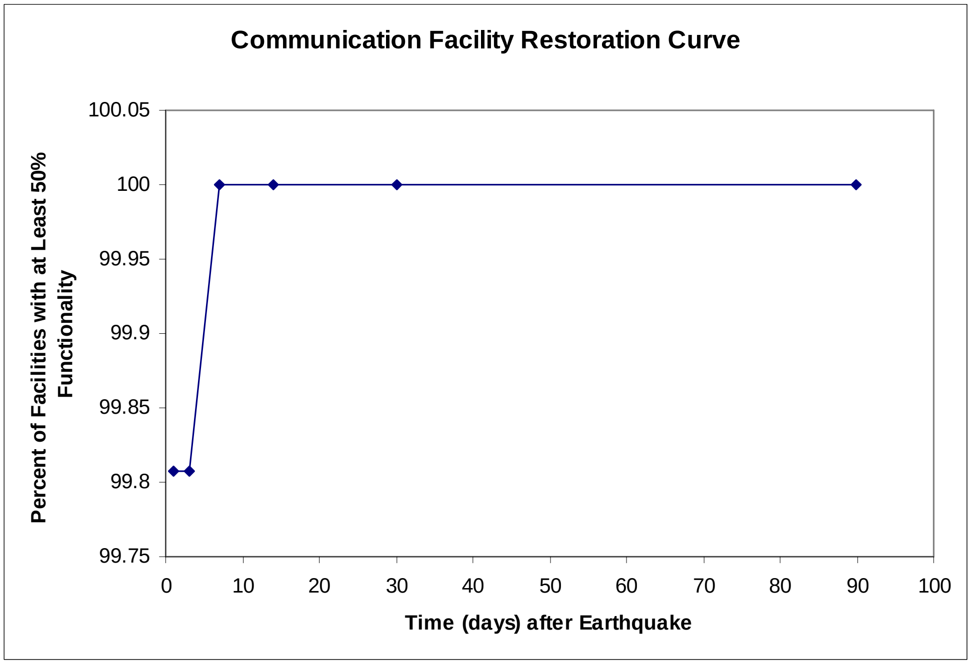


Figure 53: Communication Facility Restoration Curve

4.2.3.6 Total Losses to the Utility Lifeline System

The total loss for the utility system inventory, including facilities and distribution lines, was estimated to be $1.16 billion. The loss estimate was dominated by the $909 million loss to wastewater facilities and distribution lines. This loss estimate for the wastewater system was much higher than that for any of the other utility systems because there are many more wastewater facilities than any other utility, and therefore much more inventory value for wastewater facilities, in the study region. Although the loss estimate for the wastewater system is so large, this estimate is only slightly over one percent of the total utility system inventory value. This loss estimate is relatively low. The loss ratios for all utility system components can be found in the direct economic losses section of this chapter.

4.2.4 Transportation Systems

The estimated transportation system damage is summarized in Table 16. Note that the damage for all road segments, railroad segments, and runways is zero. The damage to road segments, as estimated by HAZUS, is based on the permanent ground deformation, which is a result of liquefaction. The effect of liquefaction was not included in this preliminary HAZUS analysis, and the zero damage estimates to segments is due to the fact that liquefaction was not included. The effects of liquefaction are discussed in Chapter 6 of this report.

Table 16: Expected Damage to the Transportation System

System	Component	Locations/ Segments	With at Least Mod. Damage		With Complete Damage		With Functionality > 50 % After Day 1		With Functionality > 50 % After Day 7	
			Count	%	Count	%	Count	%	Count	%
Highway	Segments	4,333	0	0.0	0	0.0	4,269	98.5	4,269	98.5
	Bridges	22,854	66	0.3	6	0.0	22,794	99.7	22,813	99.8
	Tunnels	0	0	--	0	--	0	--	0	--
Railways	Segments	8,441	0	0.0	0	0.0	8,441	100.0	8,441	100.0
	Bridges	963	0	0.0	0	0.0	963	100.0	963	100.0
	Tunnels	0	0	--	0	--	0	--	0	--
	Facilities	285	3	1.1	0	0.0	282	98.9	285	100.0
Light Rail	Segments	30	0	0.0	0	0.0	30	100.0	30	100.0
	Bridges	38	0	0.0	0	0.0	38	100.0	38	100.0
	Tunnels	0	0	--	0	--	0	--	0	--
	Facilities	0	0	--	0	--	0	--	0	--
Bus	Facilities	101	0	0.0	0	0.0	101	100.0	101	100.0
Ferry	Facilities	2	2	100.0	2	100.0	0	0.0	0	0.0
Port	Facilities	438	11	2.5	0	0.0	427	97.5	434	99.1
Airport	Facilities	624	2	0.3	0	0.0	623	99.8	623	99.8
	Runways	705	0	0.0	0	0.0	705	100.0	705	100.0

4.2.4.1 Highway Bridges, Segments, and Tunnels

The estimated damage to highway bridges is shown on the map in Figure 54 as the probability of exceeding moderate damage for each highway bridge in the inventory. HAZUS estimates that 66 highway bridges suffer at least moderate damage. The functionality of highway bridges is summarized in Table 17. There are no estimates for highway tunnel damage because no tunnels exist in the HAZUS default inventory.

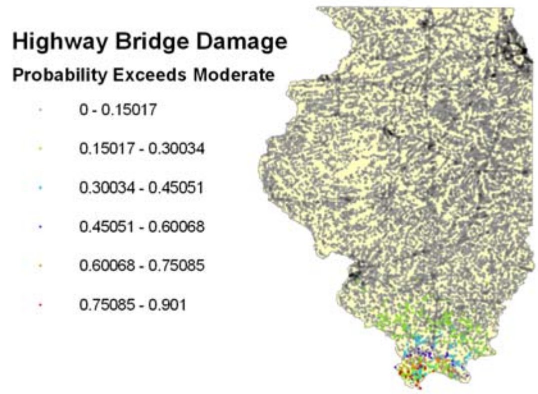


Figure 54: Highway Bridge Damage Probability of Exceeding Moderate

Table 17: Functionality of Highway Bridges

Functionality of Highway Bridges										
	At Day 1		At Day 3		At Day 7		At Day 30		At Day 90	
Percent Functional	**Count**	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**
60 - 70%	184	0.8	184	0.8	0	0.0	0	0.0	0	0.0
70% - 80%	0	0.0	0	0.0	184	0.8	184	0.8	0	0.0
80% - 90%	470	2.1	174	0.8	103	0.5	103	0.5	184	0.8
90% - 100%	22200	97.1	22496	98.4	22567	98.7	22567	98.7	22670	99.2

Figure 55 illustrates the restoration of highway bridge functionality. The percent of the total number of highway bridges with a functionality of at least 50% on the day of the earthquake, 3 days, 7 days, 14 days, 30 days, and 90 days after the earthquake are plotted.

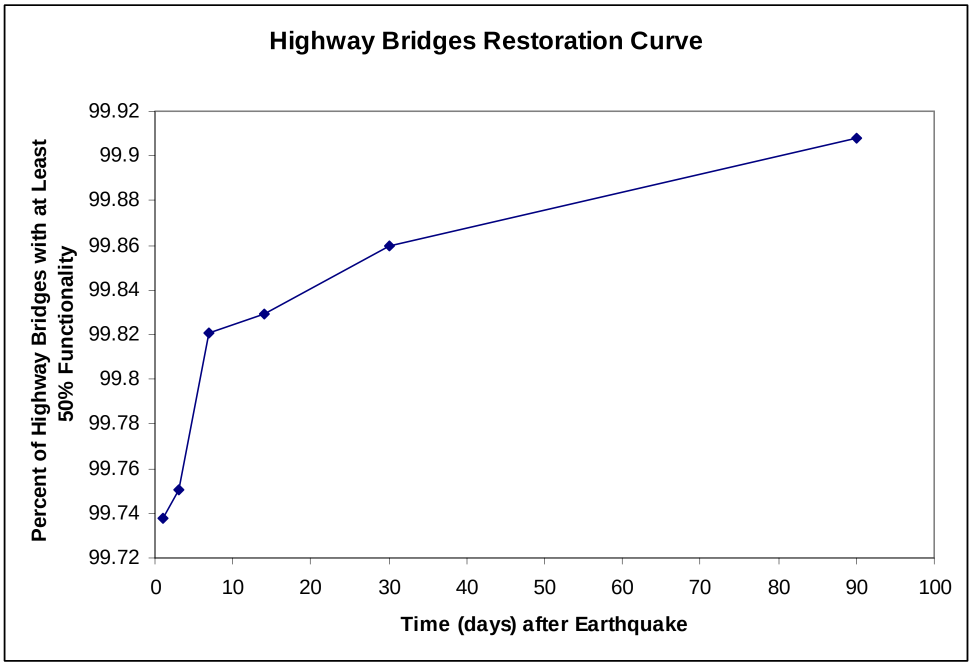


Figure 55: Highway Bridges Restoration Curve

The damage to highway segments is shown on the map in Figure 56. Note that the damage is zero for all highway segments because liquefaction was not included in this analysis. The damage to roads depends only on the peak ground deformation, which is a result of liquefaction.

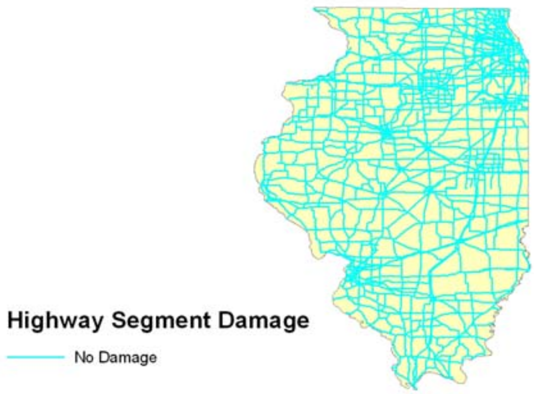


Figure 56: Highway Segment Damage

The functionality of highway roads, as estimated by HAZUS, is shown in Table 18. A very small percentage of highways are not fully functional immediately after the earthquake. The high functionality is due to the fact that liquefaction was not included in the level 1 analysis, and the peak ground deformation is estimated to be zero.

Table 18 : Highway Road Functionality at Day 1

Highway Road Functionality at Day 1		
Percent Functional	**km**	**Percent of Total**
60 - 70%	54	0.2
70% - 80%	0	0.0
80% - 90%	765	3.3
90% - 100%	22468	96.5

4.2.4.2 Railway Bridges, Segments, Tunnels, and Facilities

The estimated damage to railway bridges is shown on the map in Figure 57. The damage to railway segments is shown on the map in Figure 58. HAZUS estimated that no railway bridges suffer at least moderate damage. Note that the damage is zero for all railway segments because liquefaction was not included in this analysis. This is similar to the roadway damage estimates. There are no damage estimates for railway tunnel damage because no such tunnels exist in the HAZUS default inventory.

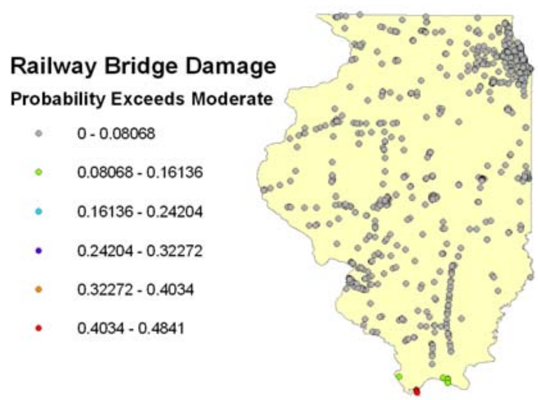


Figure 57: Railway Bridge Damage Probability of Exceeding Moderate

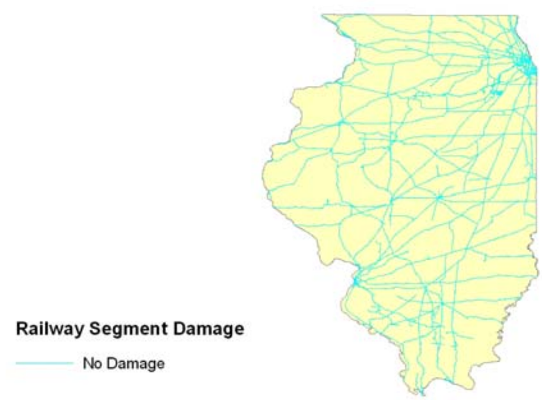


Figure 58: Railway Segment Damage

Figure 59 illustrates the restoration of railway facility functionality. The percent of the total number of railway facilities with a functionality of at least 50% on the day of the earthquake, 3 days, 7 days, 14 days, 30 days, and 90 days after the earthquake are plotted.

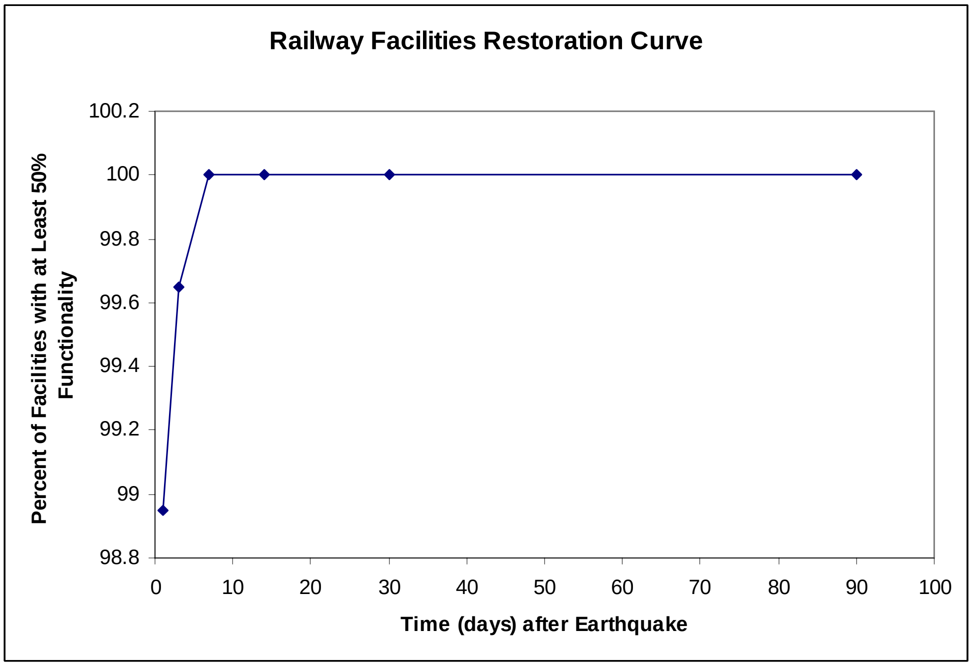


Figure 59: Railway Facilities Restoration Curve

4.2.4.3 Light Rail Bridges, Segments, Tunnels, and Facilities

HAZUS estimates no damage to the components of the light rail transportation system because all segments are located in Northern Illinois in the Chicago Metropolitan area. There are no damage estimates for light rail tunnels or light rail facilities because these are not included in the HAZUS default inventory.

4.2.4.4 Bus Facilities

The estimated probability of exceeding moderate damage for all bus facilities in Illinois is shown in Figure 60. HAZUS estimated that no bus facilities will suffer at least moderate damage, so the bus transportation system will depend largely on the highway road and bridge conditions.

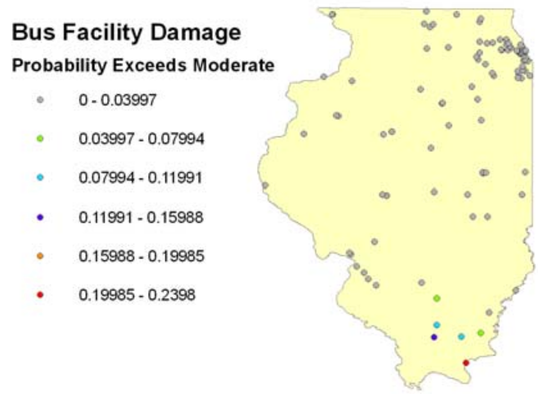


Figure 60: Bus Facility Damage Probability of Exceeding Moderate Damage

4.2.4.4 Ports

The estimated probability of exceeding moderate damage for all port facilities in Illinois is shown in Figure 61. It was estimated that of the over 400 port facilities in the state of Illinois, 11 facilities will suffer at least moderate damage.

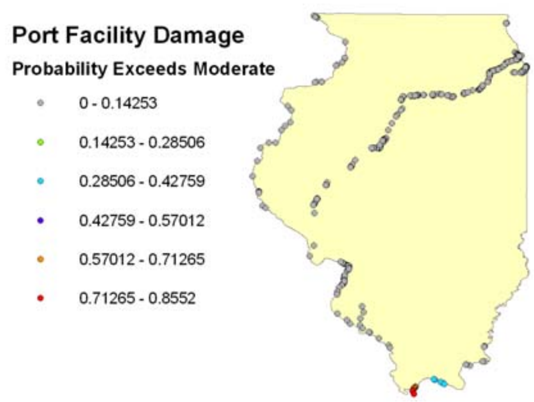


Figure 61: Port Facility Damage Probability of Exceeding Moderate Damage

Figure 62 illustrates the restoration of port facility functionality. The percent of the total number of port facilities with a functionality of at least 50% on the day of the earthquake, 3 days, 7 days, 14 days, 30 days, and 90 days after the earthquake are plotted.

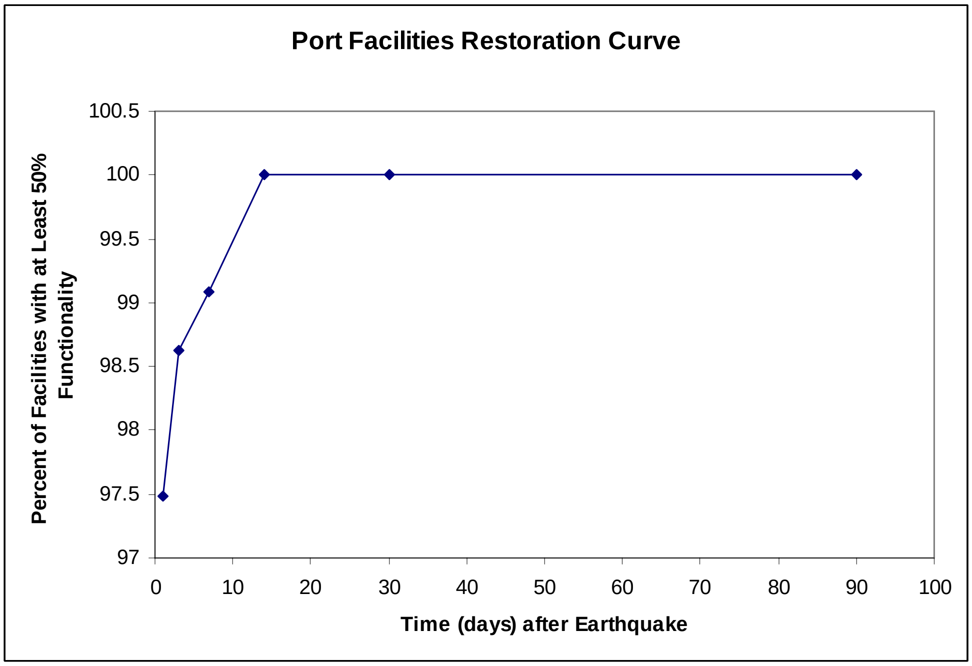


Figure 62: Port Facilities Restoration Curve

4.2.4.5 Airport Facility/Runway

The estimated probability of exceeding moderate damage for all airport facilities in Illinois is shown in Figure 63. HAZUS estimated that two airports of the over 600 in the state of Illinois, two airports in the southern most part of Illinois would suffer at least moderate damage. It was estimated there would be no runway damage because liquefaction was not included in this analysis, similar to the damage to highway segments and railway segments.

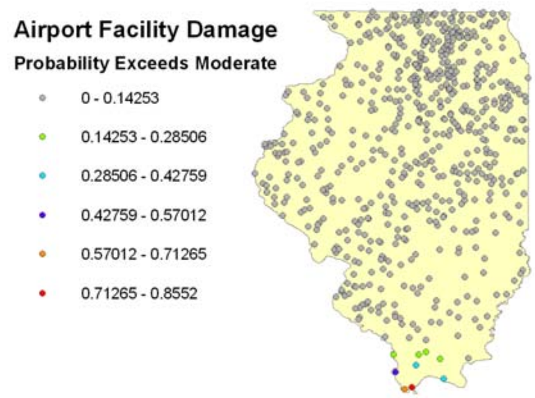


Figure 63: Airport Facility Damage Probability of Exceeding Moderate

Figure 64 illustrates the restoration of airport facility functionality. The percent of the total number of airport facilities with a functionality of at least 50% on the day of the earthquake, 3 days, 7 days, 14 days, 30 days, and 90 days after the earthquake are plotted.

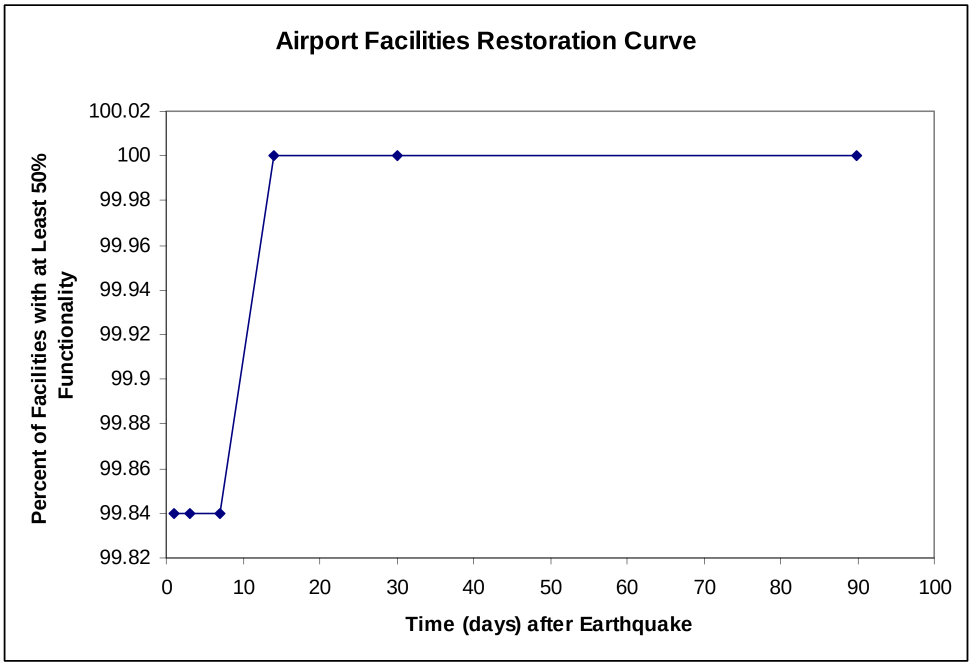


Figure 64: Airport Facilities Functionality

4.3 Social Losses

4.3.1 Injuries and Casualties

HAZUS gives estimates for four levels of injury severity. The definition of the injury severities is given in Table 19.

Table 19: Injury Severity Definitions in HAZUS (FEMA, 2006b)

Injury Severity	Injury Description
Severity 1	Injuries requiring basic medical aid without requiring hospitalization
Severity 2	Injuries requiring a greater degree of medical care and hospitalization, but not expected to progress to a life threatening status
Severity 3	Injuries that pose an immediate life threatening condition if not treated adequately and expeditiously. The majority of these injuries are a result of structural collapse and subsequent collapse or impairment of the occupants.
Severity 4	Instantaneously killed or mortally injured

Table 20 shows the number of injuries estimated to occur if the scenario earthquake occurred during the night (2 am), during the afternoon (2 pm), and during commute time (5 pm). The total number of people estimated to seek medical aid (i.e., the number of people suffering from level 2 and level 3 injuries) is approximately 350 people, 320 people, and 330 people if the scenario event occurred at 2 am, 2 pm, or 5 pm, respectively.

Table 20: Injury Estimates

		Level 1	Level 2	Level 3	Level 4
2 AM	Commercial	8	2	0	0
	Commuting	0	0	0	0
	Educational	0	0	0	0
	Hotels	10	2	0	1
	Industrial	11	2	0	1
	Other-Residential	666	124	11	20
	Single Family	811	183	25	49
	Total	**1,506**	**314**	**37**	**70**
2 PM	Commercial	614	131	16	31
	Commuting	1	1	1	0
	Educational	231	53	7	14
	Hotels	2	0	0	0
	Industrial	83	18	2	4
	Other-Residential	145	28	3	5
	Single Family	204	48	7	13
	Total	**1,279**	**280**	**37**	**68**
5 PM	Commercial	556	121	15	29
	Commuting	10	13	22	4
	Educational	36	7	1	2
	Hotels	3	1	0	0
	Industrial	52	11	1	3
	Other-Residential	246	47	4	8
	Single Family	325	76	11	20
	Total	**1,228**	**276**	**55**	**66**

4.3.2 Uninhabitable Homes

The number of uninhabitable homes is estimated using the number of displaced households as estimated by the loss estimation tool. HAZUS estimated that over 2,800 households would be displaced due to the scenario event and from these households, 860 people out of a total population of over 12 million would seek short term public shelter. HAZUS assumes that a household consists of 2.5 people; therefore, about 12% of displaced people are expected to seek public shelter. Table 21 summarizes the shelter needs.

Table 21: Shelter Needs

Shelter Needs			
Displaced Households		People Needing Short Term Shelter	
Number	% of Households	Number	% of Population
2,876	0.06	860	0.01

4.3.3 Uninhabitable Commercial and Public Buildings

Commercial and public buildings are those that are assigned the Commercial, Education, or Government HAZUS occupancy classes. It was assumed that an uninhabitable building is a building in which the structural damage reaches or exceeds the Moderate Limit State. The total number uninhabitable commercial buildings is 721, and total number uninhabitable public buildings is 63 (the total of Education and Government occupancy classes).

Table 22: Uninhabitable Commercial and Public Buildings

	Moderate		Extensive		Complete		Total	
Occupancy	# of Buildings	% of Occupancy	# of Buildings	% of Occupancy	# of Buildings	% of Occupancy	# of Buildings	% of Occupancy
Commercial	510	1.22	174	0.42	37	0.09	721	1.72
Education	6	1.69	2	0.56	1	0.28	9	2.53
Government	36	2.46	12	0.82	5	0.34	53	3.62

4.4 Economic Loss Estimates

The loss estimates for the general building stock, essential facilities, transportation systems, and utility systems are discussed in the following sections.

4.4.1 General Building Stock

The building-related economic loss estimates include both income losses and capital stock losses. Included in the income losses are wage losses, capital-related losses, rental losses, and relocation losses. These losses include business interruption losses and the losses associated with inability to operate a business because of the damage sustained during the earthquake. Similarly, included in the capital stock losses are losses due to structural damage, non-structural damage, content damage, and inventory damage. These include estimated costs to repair or replace the damage caused to the building and its contents. The income losses and capital stock losses for buildings are summarized in Table 23. The losses are subdivided into occupancy classes. The majority of income losses (about 70% of the total income loss) occur in the commercial occupancy class. Most of the capital stock losses occur in the residential occupancies of Single Family Homes and Other Residential (about 60% of the total capital stock losses). The greatest loss within the capital stock losses is the loss due to non-structural damage.

Table 23: Building-Related Economic Loss Estimates (Millions of dollars)

Category	Area	Single Family	Other Residential	Commercial	Industrial	Others	Total
Income Loses							
	Wage	0.00	4.27	94.68	2.73	6.91	108.59
	Capital-Related	0.00	1.86	77.57	1.77	1.99	83.19
	Rental	32.87	31.59	42.19	0.95	3.16	110.77
	Relocation	3.66	1.34	2.73	0.11	0.99	8.83
	Subtotal	**36.53**	**39.06**	**217.17**	**5.56**	**13.06**	**311.38**
Capital Stock Loses							
	Structural	152.78	107.22	99.66	14.93	28.10	402.69
	Non_Structural	464.03	294.61	180.90	29.32	57.61	1,026.47
	Content	139.42	52.16	73.08	17.19	25.43	307.28
	Inventory	0.00	0.00	3.10	3.76	0.66	7.52
	Subtotal	**756.23**	**453.99**	**356.73**	**65.20**	**111.80**	**1,743.96**
	Total	**792.76**	**493.05**	**573.91**	**70.77**	**124.86**	**2,055.35**

4.4.2 Lifeline Systems

HAZUS does not compute losses due to business interruption due to lifeline outages for the transportation and utility systems. The loss estimation tool estimates only the repair costs for each transportation and utility lifeline system component. This differs from the loss estimates for buildings. The direct economic losses to the lifeline systems are discussed in the following sections.

4.4.2.1 Transportation Systems

Table 24 summarizes the losses (repair costs) for the transportation system components, and Table 25 summarizes the losses (repair costs) for the utility system components. The total loss for the transportation systems is estimated to be $211 million. The largest contribution to the total loss estimate is from the losses due to the damage of highway bridges. The highway bridge losses dominate because of the significantly large number of bridges in the inventory.

The loss to segments is very low because damage to segments depends on peak ground deformation, which results from liquefaction. Liquefaction was not accounted for in the level 1 analysis.

Table 24: Transportation System Economic Losses (Millions of Dollars)

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Highway	Segments	95,066.33	1.00	0.00
	Bridges	21,107.01	109.13	0.52
	Tunnels	0.00	0.00	0.00
	Subtotal	**116173.34**	**109.13**	
Railways	Segments	11,844.99	0.00	0.00
	Bridges	110.98	0.18	0.16
	Tunnels	0.00	0.00	0.00
	Facilities	689.64	11.02	1.60
	Subtotal	**12645.61**	**11.19**	
Light Rail	Segments	124.88	0.00	0.00
	Bridges	4.80	0.00	0.00
	Tunnels	0.00	0.00	0.00
	Facilities	0.00	0.00	0.00
	Subtotal	**129.67**	**0.00**	
Bus	Facilities	122.20	1.59	1.30
	Subtotal	**122.20**	**1.59**	
Ferry	Facilities	2.42	2.42	100.00
	Subtotal	**2.42**	**2.42**	
Port	Facilities	983.49	27.59	2.80
	Subtotal	**983.49**	**27.59**	
Airport	Facilities	3,774.89	59.57	1.58
	Runways	24,321.65	0.00	0.00
	Subtotal	**28096.54**	**59.57**	
	Total	**158153.27**	**211.49**	

4.4.2.2 Utility Systems

The losses to the utility systems inventory in the State of Illinois are summarized below. The total loss to the utility systems is estimated to be $1.16 billion, with over half of that coming from the wastewater utility system. The estimated loss to all pipelines is zero because HAZUS does not assign a replacement cost to the pipeline inventories. Table 25 summarizes the utility system economic losses.

Table 25: Utility System Economic Losses (Millions of Dollars)

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Potable Water	Pipelines	0.00	0.00	0.00
	Facilities	8,945.05	87.64	0.98
	Distribution	5,307.95	35.21	0.66
	Subtotal	**14,253.00**	**122.85**	
Waste Water	Pipelines	0.00	0.00	0.00
	Facilities	64,759.18	880.60	1.36
	Distribution	3,184.77	27.85	0.87
	Subtotal	**67,943.95**	**908.45**	
Natural Gas	Pipelines	0.00	0.00	0.00
	Facilities	75.01	1.00	1.33
	Distribution	2,123.18	29.77	1.40
	Subtotal	**2,198.20**	**30.77**	
Oil Systems	Pipelines	0.00	0.00	0.00
	Facilities	4.33	0.01	0.26
	Subtotal	**4.33**	**0.01**	
Electrical Power	Facilities	18,681.30	101.59	0.54
	Subtotal	**18,681.30**	**101.59**	
Communication	Facilities	57.50	0.52	0.90
	Subtotal	**57.50**	**0.52**	
	Total	**103,138.27**	**1,164.19**	

4.5 Indirect Losses

HAZUS estimates the long-term economic impacts to the region for 15 years after the earthquake. The long-term economic impacts information is in terms of income and employment changes in the study region. The economic impacts with outside aid are summarized in Table 26. Values in parentheses indicate gains, as opposed to losses. HAZUS estimated that by five years after the earthquake, there would be no remaining negative income impact, and by six years after the earthquake, there would be no remaining negative employment impact.

Table 26: Indirect Economic Impact with Outside Aid (Employment as # of people and Income in millions of $)

	LOSS	Total	%
First Year			
	Employment Impact	2,537,366	67.27
	Income Impact	11,646	4.99
Second Year			
	Employment Impact	847,779	22.48
	Income Impact	5,751	2.46
Third Year			
	Employment Impact	18,972	0.50
	Income Impact	1,486	0.64
Fourth Year			
	Employment Impact	1,070	0.03
	Income Impact	20	0.01
Fifth Year			
	Employment Impact	58	0.00
	Income Impact	(62)	-0.03
Years 6 to 15			
	Employment Impact	0	0.00
	Income Impact	(67)	-0.03

4.6 Induced Damage and Secondary Disasters

4.6.1 Dam and Dike Failures

Dam and dike failures are not analyzed by HAZUS unless inundation maps are provided. Inundation maps have not been provided for this Level 1 analysis.

4.6.2 Fire Following Earthquake

HAZUS estimates that there will be 19 fire ignitions, and these fires will burn approximately 0.18 square miles. This area is less than 0.01% of the entire study region area. The fire is expected to burn about $1.6 million of building value. The results of the Fire Following Earthquake Module are summarized in Table 27 and Figure 65.

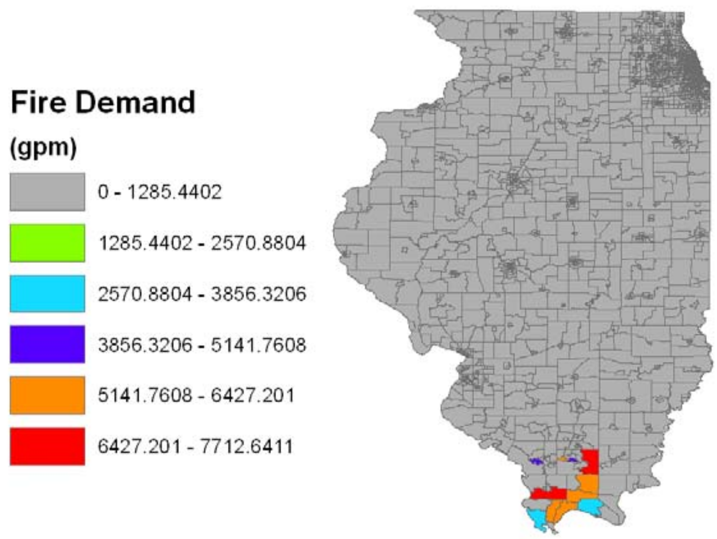


Figure 65: Fire Demand (gpm)

Table 27: Fire Following Earthquake Module Results

Fire Following Earthquake		
Number of Ignitions	**Population Exposed**	**Value Exposed (thous. $)**
19	27	1,621

4.6.3 Hazardous Material Release

HAZUS does not estimate the likelihood of hazardous material spills unless a large amount of user-supplied data is provided. According to the HAZUS Technical Manual, there exist no usable methodologies to predict hazardous materials release that could be incorporated into the HAZUS methodology.

4.6.4 Debris

HAZUS estimates two types of debris generated by the scenario earthquake: 1) Brick, Wood and Others and 2) Concrete and Steel. This distinction is made because of the different types of material handling equipment required to remove the debris. HAZUS estimates that it will require approximately 40,000 truckloads (at 25 tons/truck) to remove the debris generated by the scenario event. The distribution of total debris is mapped in Figure 66.

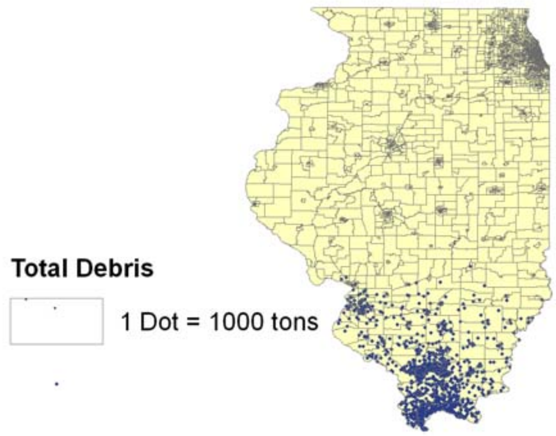


Figure 66: Total Debris Distribution

Table 28: Debris Totals

Debris (thousands of tons)		
Brick, Wood & Others	**Concrete & Steel**	**Total**
795	661	1,456

4.7 Summary of Losses

HAZUS estimated that the total economic loss to the State of Illinois caused by the scenario event is approximately $3.4 billion. This total includes $1.74 billion in building-related capital stock losses, $311 million in building-related income losses, $212 million in transportation system direct economic losses, and $1.16 billion in utility system direct economic losses.

The loss estimate for the utilities lifeline system is likely underestimated because the damage to pipelines was not calculated by this HAZUS level 1 analysis. Similarly, the loss estimate for the transportation system is likely underestimated because HAZUS does not estimate damage to road or railway segments unless liquefaction is included in the analysis. In addition, no tunnels or light rail facilities are contained in the HAZUS default transportation systems inventory. The light rail system components that do exist in the HAZUS inventory are concentrated in the Chicago Metropolitan area, so it would be unlikely that an earthquake in the NMSZ would damage the light rail facilities even if they were included in the HAZUS default inventory. The losses to the communication system are also likely underestimated because HAZUS does not estimate damage to electric power lines or any type of communication lines. In addition, the losses to the telephone communication system were not estimated because they are not contained in the HAZUS default inventory.

5. Effects of Soil Site Condition

This chapter describes a HAZUS analysis in which the effects of local site class were used in the ground motion calculations. The resulting damage and loss estimates are also described.

5.1 Soil Site Classes in Illinois

A site class map for the southern one-third of Illinois was provided by the Illinois State Geological Survey (Bauer, 1999). The map is pictured in Figure 67. The mapped soil types are soft soils, stiff soils, very dense soils and soft rock, rock, and hard rock. The site classes were determined using shear wave velocities for the surficial soil materials. Existing three-dimensional maps and base geological maps of the surficial soils, when available, were included in the study used to develop the soil maps (Bauer, 1999).

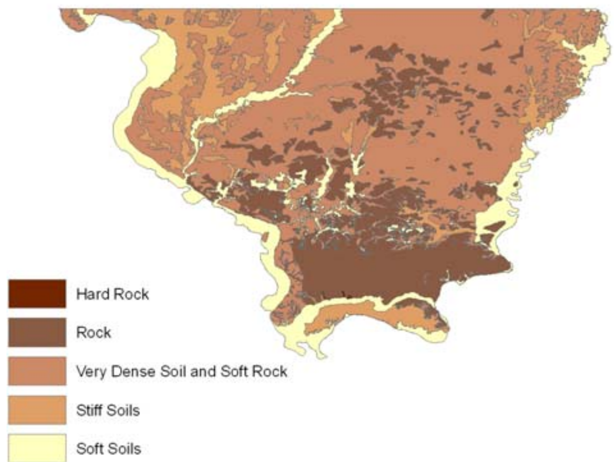


Figure 67: Site Classes for Southern Illinois

The NEHRP site class factors were used to account for site class effects. The factors were implemented into the ground motion program, as described in the hazard section of this report.

Because the soil maps provided by ISGS specified site classes only the southern one-third of Illinois, the effect of the site class was only studied for counties lying within that region. The counties that were studied for the effects of site class are pictured in Figure 68.

Figure 68: Counties Studied for Site Class Effects

5.2 Site Class Effects for Southern Illinois

The size of this study region of 279 census tracts in southern Illinois is 12,982 square miles. According to the HAZUS general building stock inventory, there are approximately 440,000 households with over 1.1 million people. The total replacement cost in the HAZUS general building stock inventory is estimated to be approximately 60 billion dollars for over 360,000 total buildings. A vast majority (99%) of the general building stock is residential housing. The total value of the transportation systems and the utility systems are $30 billion and $22 billion, respectively.

The HAZUS inventory of Essential Facilities contains 45 hospitals, 587 schools, 188 fire stations, 154 police stations and 26 emergency operation centers. The hospitals are estimated to have a capacity of 5,157 beds.

5.2.1 Ground Motion

The ground motion program discussed in the Hazard Definition chapter of this report was used to calculate the PGA, PGV, S_a at 0.3 second, and S_a at 1.0 second for each census tract in the study region. This was done for both the study region with the local site classes and the study region with a uniform site class D because HAZUS assumes a uniform site class D for the entire study region as a default if no site class maps are imported. The scenario with a uniform site class D mimics a HAZUS default analysis. The ground motion maps (PGA, PGV, S_a at 0.3 second, and S_a at 1.0 second) for the study region with a uniform site class D are shown in Figures 69 , 70, 71, and 72 respectively.

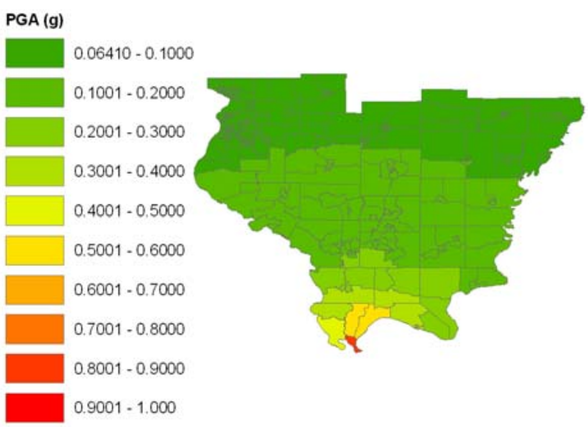


Figure 69: PGA, Constant Soil Type D

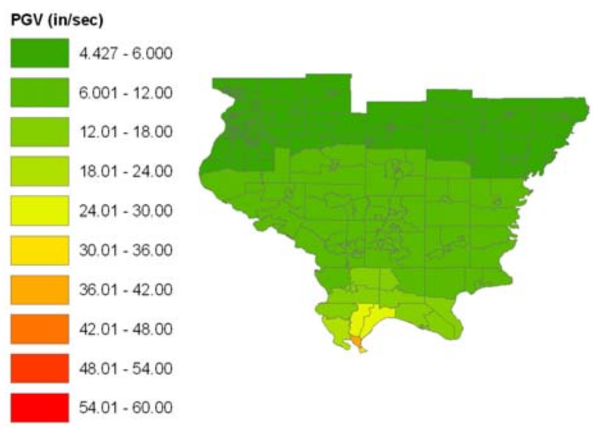


Figure 70: PGV, Constant Soil Type D

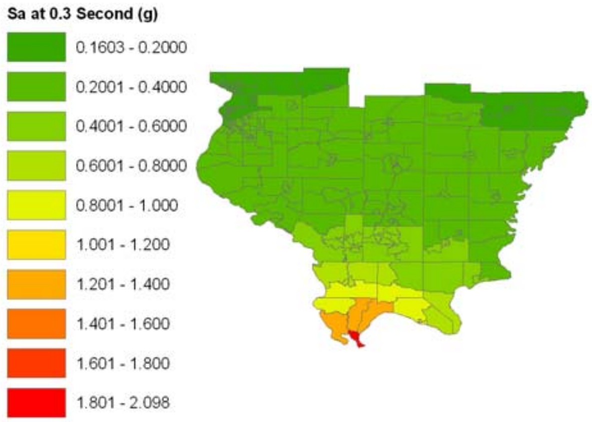


Figure 71: Sa at 0.3 Second, Constant Soil Type D

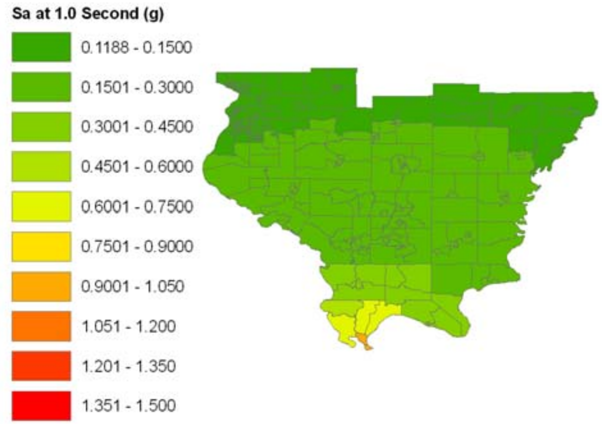


Figure 72: Sa at 1.0 Second, Constant Soil Type D

The ground motion was computed for the same study region using the local site classes provided by ISGS (Bauer, 1999). The effects of site classes are compared with an analysis of a uniform site class D. According to the *NEHRP Provisions* (FEMA, 2003), the ground motion amplification factors are higher for site class D than for site classes A, B, and C because these soil types are stiffer than type D. The ground motion amplification factor is higher for site class E than for site class D because soil type E is less stiff than type D. Therefore, only portions of the study region with site class E soils will have larger ground motion parameters than the default site class D analysis, and the portions of the study region with site classes A, B, or C will have smaller ground motion parameters than the default run. Figure 73 shows the locations of type E soils, and Figure 74 shows the locations of type A, B, or C soils.

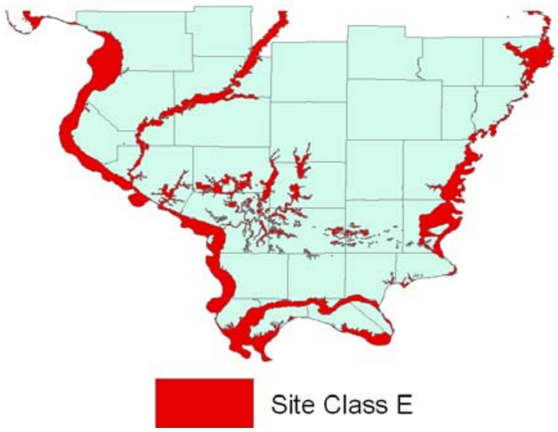


Figure 73: Locations of Site Class E (Ground Motion Expected to Increase)

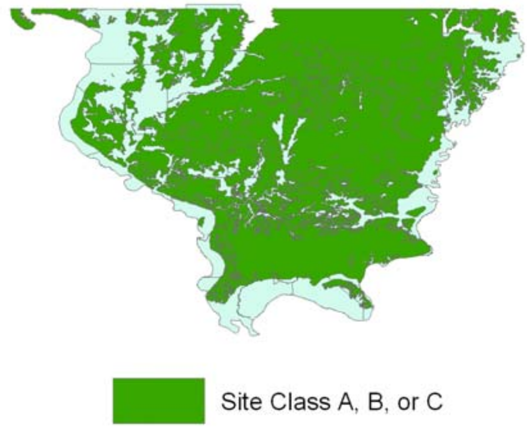


Figure 74: Locations of Site Classes A, B, or C (Ground Motion Expected to Decrease)

The resulting ground motion maps are shown in Figures 75, 76, 77, and 78 for PGA, PGV, S_a at 0.3 second, and S_a at 1.0 second, respectively. It was expected that damage reduced in the case that the site class effects were included because the ground motion was reduced over a majority of the study region.

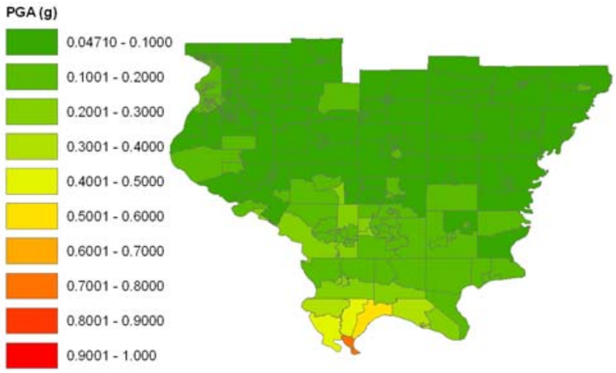


Figure 75: PGA Accounting for Local Site Effects

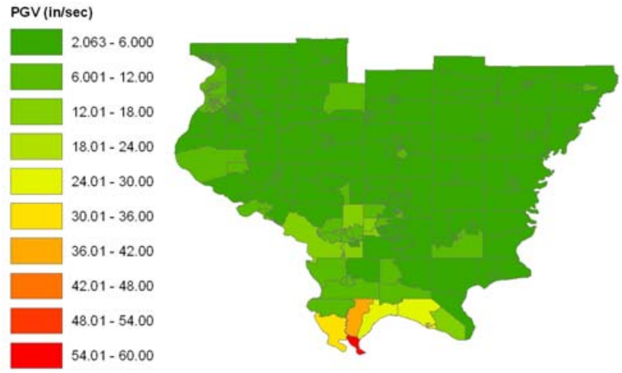


Figure 76: PGV Accounting for Local Site Effects

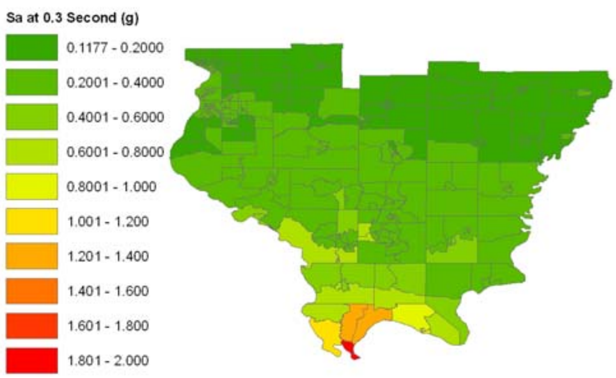


Figure 77: Sa at 0.3 Second Accounting for Local Site Effects

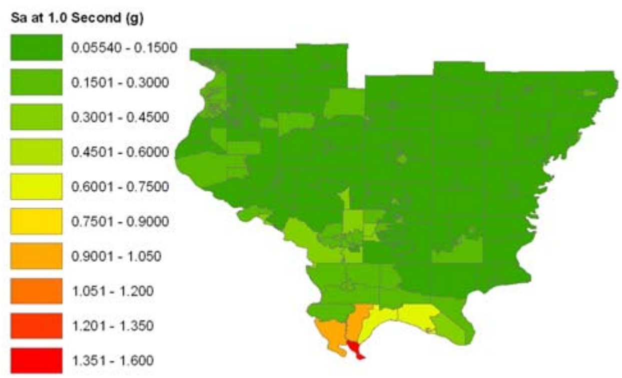


Figure 78: Sa at 1.0 Second Accounting for Local Site Effects

Many census tracts contained soil of site class A, B, or C, so the ground motion was actually reduced for those tracts when compared with the default case with uniform site class D. Therefore, many loss estimates are reduced due to the reduced ground motion.

5.2.2 Damage Estimates

The damage estimates from HAZUS for the case with a uniform site class D and the case including the local site effects on the ground motion are compared in this section.

5.2.2.1 General Building Stock

The damage estimates for the general building stock are summarized in Tables 29 and 30 for the HAZUS analyses excluding and including site class effects, respectively. The number of buildings that suffered no damage and complete damage increased by about 8% and 29%, respectively, when the effects of local site conditions were considered. The number of buildings that were extensively damaged and moderately damaged decreased by about 48% and 27%, respectively, when the local site effects were considered.

Table 29: Building Damage by Occupancy, Uniform Site Class D

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Agriculture	25	0.01	11	0.02	11	0.03	4	0.03	2	0.06
Commercial	1,424	0.54	591	1.18	495	1.40	174	1.45	37	1.29
Education	15	0.01	6	0.01	6	0.02	2	0.02	1	0.03
Government	77	0.03	37	0.07	35	0.10	12	0.10	5	0.17
Industrial	118	0.04	55	0.11	56	0.16	19	0.16	3	0.11
Other Residential	19,091	7.18	12,850	25.57	20,810	58.80	8,084	67.32	1,543	54.08
Religion	154	0.06	45	0.09	38	0.11	16	0.13	5	0.18
Single Family	245,034	92.14	36,656	72.94	13,941	39.39	3,698	30.79	1,258	44.09
Total	**265,938**		**50,252**		**35,392**		**12,008**		**2,854**	

Table 30: Building Damage by Occupancy, Accounting for Local Site Effects

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Agriculture	36	0.01	8	0.02	5	0.02	2	0.02	2	0.06
Commercial	1,685	0.59	542	1.21	351	1.42	99	1.58	43	1.16
Education	17	0.01	5	0.01	4	0.02	1	0.02	1	0.04
Government	93	0.03	37	0.08	27	0.11	6	0.10	4	0.11
Industrial	153	0.05	45	0.10	38	0.16	10	0.17	4	0.11
Other Residential	27,577	9.61	14,752	32.89	14,236	57.62	3,834	61.18	1,979	53.70
Religion	176	0.06	41	0.09	26	0.11	8	0.13	6	0.17
Single Family	257,200	89.64	29,417	65.59	10,018	40.55	2,306	36.80	1,646	44.66
Total	**286,937**		**44,849**		**24,706**		**6,267**		**3,685**	

5.2.2.2 Essential Facilities

In the case that local site effects were considered, 5 fewer hospitals, 48 fewer schools, 2 fewer emergency operation centers, 13 fewer police stations, and 15 fewer fire stations were expected to suffer at least moderate damage. The reduction in damage to essential facilities occurred because the ground motion parameters for many census tracts reduced when the site class effects were included. The ground motion reduced when soil site effects were included because the soil types in the majority of census tracts were A, B, or C (see Figure 74). The ground motion reduced in these regions because the soils are stiffer than site class D, which is used in a default HAZUS analysis. The expected damage to essential facilities is summarized in Tables 31 and 32 for the uniform site class D and for the local site effects, respectively.

Table 31: Damage to Essential Facilities, Uniform Site Class D

Classification	Total # of Facilities	With at Least Moderate Damage		With Complete Damage		With Functionality > 50% on day 1	
		Count	%	Count	%	Count	%
Hospitals	45	16	35.6	1	2.2	24	53.3
Schools	587	91	15.5	9	1.5	431	73.4
EOCs	26	5	19.2	2	7.7	20	76.9
PoliceStations	154	36	23.4	6	3.9	93	60.4
FireStations	188	37	19.7	7	3.7	119	63.3

Table 32: Damage to Essential Facilities, Accounting for Local Site Effects

Classification	Total # of Facilities	With at Least Moderate Damage		With Complete Damage		With Functionality > 50% on day 1	
		Count	%	Count	%	Count	%
Hospitals	45	11	24.4	1	2.2	28	62.2
Schools	587	43	7.3	18	3.1	434	73.9
EOCs	26	3	11.5	2	7.7	19	73.1
PoliceStations	154	23	14.9	8	5.2	105	68.2
FireStations	188	22	11.7	10	5.3	142	75.5

5.2.2.3 Transportation Systems

The number of highway bridges expected to suffer moderate damage and complete damage increased by 45 and 18 bridges, respectively, when local site effects were considered. The number of railway bridges and facilities expected to be at least moderately damaged increased from zero to five and three to five, respectively, when site class effects were added. The same number of port facilities and airport facilities were expected to suffer at least moderate damage in both cases. Tables 33 and 34 show the expected damage to the transportation system lifelines for the case in which site classes are not considered and the case in which site classes are considered, respectively.

Table 33: Damage to Transportation Systems, Uniform Site Class D

System	Component	Locations/ Segments	With at Least Mod. Damage		With Complete Damage		With Functionality > 50 % After Day 1		With Functionality > 50 % After Day 7	
			Count	%	Count	%	Count	%	Count	%
Highway	Segments	816	0	0.0	0	0.0	807	98.9	807	98.9
	Bridges	4,810	66	1.4	6	0.1	4,750	98.8	4,769	99.1
Railways	Segments	1,658	0	0.0	0	0.0	1,658	100.0	1,658	100.0
	Bridges	163	0	0.0	0	0.0	163	100.0	163	100.0
	Facilities	55	3	5.5	0	0.0	52	94.5	55	100.0
Light Rail	Segments	1	0	0.0	0	0.0	1	100.0	1	100.0
Bus	Facilities	15	0	0.0	0	0.0	15	100.0	15	100.0
Port	Facilities	92	11	12.0	0	0.0	81	88.0	88	95.7
Airport	Facilities	81	2	2.5	0	0.0	80	98.8	80	98.8
	Runways	99	0	0.0	0	0.0	99	100.0	99	100.0

Table 34: Damage to Transportation Systems, Accounting for Local Site Effects

System	Component	Locations/ Segments	With at Least Mod. Damage		With Complete Damage		With Functionality > 50 % After Day 1		With Functionality > 50 % After Day 7	
			Count	%	Count	%	Count	%	Count	%
Highway	Segments	816	0	0.0	0	0.0	807	98.9	807	98.9
	Bridges	4,810	111	2.3	24	0.5	4,706	97.8	4,763	99.0
Railways	Segments	1,658	0	0.0	0	0.0	1,658	100.0	1,658	100.0
	Bridges	163	5	3.1	0	0.0	158	96.9	158	96.9
	Facilities	55	5	9.1	0	0.0	52	94.5	55	100.0
Light Rail	Segments	1	0	0.0	0	0.0	1	100.0	1	100.0
Bus	Facilities	15	0	0.0	0	0.0	15	100.0	15	100.0
Port	Facilities	92	11	12.0	0	0.0	81	88.0	92	100.0
Airport	Facilities	81	2	2.5	0	0.0	80	98.8	81	100.0
	Runways	99	0	0.0	0	0.0	99	100.0	99	100.0

5.2.2.4 Utility Systems

Tables 35 and 36 show the expected utility system damage when a uniform site class D is assumed and when local site effects are considered. The number of potable water facilities, waste water facilities, natural gas facilities, and communication facilities that are expected to be at least moderately damaged due to the scenario event each decreased when local site effects were considered. The number of oil system facilities and electrical power facilities that are expected to be at least moderately damaged remained the same between the two cases.

Table 35: Utility System Damage, Uniform Site Class D

System	Total	With at Least Moderate Damage		With Complete Damage		with Functionality > 50 %			
						After Day 1		After Day 7	
	# of Facilities	Count	%	Count	%	Count	%	Count	%
Potable Water	50	5	10.0	0	0.0	44	88.0	50	100.0
Waste Water	233	17	7.3	0	0.0	204	87.6	231	99.1
Natural Gas	14	3	21.4	0	0.0	11	78.6	14	100.0
Oil Systems	12	0	0.0	0	0.0	12	100.0	12	100.0
Electrical Power	22	2	9.1	0	0.0	20	90.9	22	100.0
Communication	99	6	6.1	0	0.0	98	99.0	99	100.0

Table 36: Utility System Damage, Accounting for Local Site Effects

System	Total	With at Least Moderate Damage		With Complete Damage		with Functionality > 50 %			
						After Day 1		After Day 7	
	# of Facilities	Count	%	Count	%	Count	%	Count	%
Potable Water	50	1	2.0	0	0.0	49	98.0	50	100.0
Waste Water	233	14	6.0	0	0.0	202	86.7	231	99.1
Natural Gas	14	2	14.3	0	0.0	12	85.7	14	100.0
Oil Systems	12	0	0.0	0	0.0	12	100.0	12	100.0
Electrical Power	22	2	9.1	0	0.0	19	86.4	22	100.0
Communication	99	5	5.1	0	0.0	98	99.0	99	100.0

The expected utility system pipeline damage is shown in Tables 37 and 38 for the cases in which uniform site class D is assumed for the entire region and the local site effects are considered. The number of expected leaks and breaks increased by about 7.5% for each the potable water, waste water, and natural gas systems when site class effects are added to the analysis.

Table 37: Utility System Pipeline Damage, Uniform Site Class D

System	Total Pipelines Length (kms)	Number of Leaks	Number of Breaks
Potable Water	57,363	6163	1541
Waste Water	34,418	4874	1219
Natural Gas	22,945	5210	1303

Table 38: Utility System Pipeline Damage, Accounting for Local Site Effects

System	Total Pipelines Length (kms)	Number of Leaks	Number of Breaks
Potable Water	57,363	6627	1657
Waste Water	34,418	5242	1310
Natural Gas	22,945	5603	1401

The number of households without potable water and electric power service one day, three days, seven days, 30 days, and 90 days after the earthquake are shown in Tables 39 and 40. The number of households without potable water on the day of the earthquake increases by approximately 7% when the site class effects are included in the ground motion calculations. The number of households estimated to be without electric power decreased by about 17% when the effects of local soil conditions were considered.

Table 39: Potable Water and Electric Power System Performance, Uniform Site Class D

	Total # of Households	Households without Service									
		At Day 1		At Day 3		At Day 7		At Day 30		At Day 90	
		Count	%	Count	%	Count	%	Count	%	Count	%
Potable Water	438,310	13,138	3.0	5,834	1.3	1,757	0.4	0	0.0	0	0.0
Electric Power		10,754	2.5	6,474	1.5	2,540	0.6	495	0.1	15	0.0

Table 40: Potable Water and Electric Power System Performance, Accounting for Local Site Effects

	Total # of Households	Households without Service									
		At Day 1		At Day 3		At Day 7		At Day 30		At Day 90	
		Count	%	Count	%	Count	%	Count	%	Count	%
Potable Water	438,310	14,081	3.2	11,051	2.5	7,088	1.6	0	0.0	0	0.0
Electric Power		8,935	2.0	5,474	1.2	2,152	0.5	402	0.1	12	0.0

5.2.2.5 Fire Following Earthquake

When a uniform soil type D was assumed, the Fire Following Earthquake (FFE) model in HAZUS estimated that 17 total ignitions will burn about 0.10 square mile of the study region's total area. The model also estimates that the fires will displace about 34 people. When the local site effects were considered in the ground motion calculations, the FFE model estimated that 13 total ignitions will burn about 0.09 square mile of the study region's total area. The model estimated that the fires will displace about 10 people. The effects of fire were estimated to slightly decrease when site class effects were considered due to decreased PGA.

5.2.2.6 Debris

In the case that a uniform soil type D was assumed, HAZUS estimated that a 1.00 million tons of debris will be generated. Of the total amount, Brick and Wood comprises 54% of the total, with the remainder being Concrete and Steel debris. In the case that the local site effects were used in the ground motion calculations, HAZUS estimated that the same amount of total debris would be generated, and 53% of that total would be brick and wood debris.

5.2.3 Social Losses

Social losses include the number of displaced households, people seeking public shelters, injuries, and casualties. The social loss estimates from HAZUS are discussed in this section.

5.2.3.1 Displaced Households

In the case that a default site class D was assumed, HAZUS estimated that 2,875 households will be displaced due to the scenario earthquake. From these households, 859 people were predicted to seek public shelter. When site class effects were included, HAZUS estimated that 3,068 households will be displaced, and from these households, 894 people will seek public shelter. The reason the number of displaced people increased when site class effects were added was because the number of completely damage buildings increased.

5.2.3.2 Injuries and Casualties

Tables 41 and 42 show the number of casualties estimated to occur by HAZUS when site class effects are ignored and when site class effects are considered, respectively. The injuries are estimated in the cases that the earthquake would occur at 2 AM, 2 PM, and 5 PM. For each earthquake occurrence time, the number of level 1 injuries decreased and the number of levels 2, 3, and 4 increased when the site class effects were added to the ground motions. The number of level 1 injuries were estimated to decrease by 6.6%, 5.8%, and 5.6% at 2 AM, 2 PM, and 5 PM, respectively, when local soil effects were considered. The number of level 2 injuries increased by 8.0%, 8.6%, and 10.1% at the earthquake occurrence times 2 AM, 2 PM, and 5 PM, respectively. The level 3 injuries were estimated to increase by 18.9% for both 2 AM and 2PM and were estimated to increase by 24.0% at 5 PM. Finally, the number of casualties (level 4 injuries) were estimated to increase by 20%, 20.6%, and 21.2% at the earthquake occurrence times 2 AM, 2 PM, and 5 PM, respectively, when local site effects were included in the loss estimation.

Table 41: Casualty Estimates, Uniform Site Class D

		Level 1	Level 2	Level 3	Level 4
2 AM	Commercial	8	2	0	0
	Commuting	0	0	0	0
	Educational	0	0	0	0
	Hotels	10	2	0	1
	Industrial	11	2	0	1
	Other-Residential	656	124	11	20
	Single Family	804	183	25	49
	Total	**1,489**	**313**	**37**	**70**
2 PM	Commercial	607	130	16	31
	Commuting	1	1	1	0
	Educational	230	53	7	14
	Hotels	2	0	0	0
	Industrial	82	18	2	4
	Other-Residential	143	28	3	5
	Single Family	202	48	7	13
	Total	**1,266**	**279**	**37**	**68**
5 PM	Commercial	551	121	15	29
	Commuting	10	13	21	4
	Educational	36	7	1	2
	Hotels	3	1	0	0
	Industrial	51	11	1	3
	Other-Residential	242	46	4	8
	Single Family	322	76	11	20
	Total	**1,215**	**275**	**54**	**66**

Table 42: Casualty Estimates, Accounting for Local Site Effects

		Level 1	Level 2	Level 3	Level 4
2 AM	Commercial	7	2	0	0
	Commuting	0	0	0	0
	Educational	0	0	0	0
	Hotels	9	3	0	1
	Industrial	13	3	0	1
	Other-Residential	548	118	11	20
	Single Family	813	212	31	62
	Total	**1,390**	**338**	**44**	**84**
2 PM	Commercial	553	135	19	36
	Commuting	1	1	1	0
	Educational	218	59	9	18
	Hotels	2	1	0	0
	Industrial	98	26	4	7
	Other-Residential	122	27	3	5
	Single Family	199	54	8	16
	Total	**1,192**	**303**	**44**	**82**
5 PM	Commercial	522	132	19	35
	Commuting	12	18	27	5
	Educational	20	4	1	1
	Hotels	3	1	0	0
	Industrial	61	16	2	5
	Other-Residential	202	44	4	8
	Single Family	327	88	14	25
	Total	**1,147**	**303**	**67**	**80**

5.2.4 Economic Loss Estimates

The loss estimates for the general building stock, essential facilities, transportation systems, and utility systems are discussed in the following sections.

5.2.4.1 General Building Stock

The building related economic losses are shown in Tables 43 and 44 for each site class scenario. The economic losses decreased by about 16% when the site classes were considered in the ground motion estimates for each type of building related loss and each general occupancy class.

Table 43: Building Related Economic Losses, Uniform Site Class D
(Millions of Dollars)

Category	Area	Single Family	Other Residential	Commercial	Industrial	Others	Total
Income Loses							
	Wage	0.00	4.24	93.34	2.66	6.76	107.00
	Capital-Related	0.00	1.85	76.44	1.73	1.96	81.98
	Rental	32.54	31.35	41.65	0.93	3.15	109.62
	Relocation	3.62	1.32	2.70	0.11	0.99	8.73
	Subtotal	**36.16**	**38.76**	**214.13**	**5.43**	**12.85**	**307.33**
Capital Stock Loses							
	Structural	149.79	105.12	97.92	14.54	27.46	394.84
	Non_Structural	454.26	289.29	175.43	27.69	56.27	1,002.94
	Content	134.62	50.90	69.60	16.06	24.52	295.70
	Inventory	0.00	0.00	2.95	3.51	0.60	7.07
	Subtotal	**738.67**	**445.32**	**345.90**	**61.80**	**108.86**	**1,700.55**
	Total	**774.83**	**484.07**	**560.03**	**67.23**	**121.71**	**2,007.88**

Table 44: Building Related Economic Losses, Accounting for Local Site Effects (Millions of Dollars)

Category	Area	Single Family	Other Residential	Commercial	Industrial	Others	Total
Income Loses							
	Wage	0.00	2.26	66.69	1.84	5.02	75.81
	Capital-Related	0.00	0.98	55.76	1.22	1.57	59.53
	Rental	26.75	21.34	29.33	0.67	2.25	80.35
	Relocation	2.96	0.92	1.83	0.09	0.74	6.54
	Subtotal	**29.71**	**25.50**	**153.61**	**3.82**	**9.59**	**222.24**
Capital Stock Loses							
	Structural	125.23	73.25	71.63	11.49	19.80	301.40
	Non_Structural	412.10	230.29	151.05	28.84	51.34	873.62
	Content	120.11	46.68	64.80	17.58	24.22	273.39
	Inventory	0.00	0.00	2.77	3.84	0.55	7.16
	Subtotal	**657.45**	**350.22**	**290.24**	**61.75**	**95.91**	**1,455.57**
	Total	**687.16**	**375.72**	**443.85**	**65.58**	**105.49**	**1,677.81**

5.2.4.2 Transportation Systems

The economic losses to the transportation system, as estimated by HAZUS, are shown in Tables 45 and 46. The economic losses increased for highway, railway, and port transportation systems when the site class effects were added to the analysis. These economic losses increased because many highway bridges and railway components lie in census tracts where the ground motion increased with site effects. The economic losses to the bus and the airport transportation systems decreased when the site class effects were considered. The total economic losses of the transportation system have increased by 10%.

Table 45: Transportation System Economic Loss, Uniform Site Class D (Millions of Dollars)

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Highway	Segments	19,436.25	$0.00	0.00
	Bridges	4,117.78	$104.68	2.54
	Subtotal	**23554.03**	**104.68**	
Railways	Segments	2,631.05	$0.00	0.00
	Bridges	19.59	$0.18	0.90
	Facilities	133.09	$10.48	7.88
	Subtotal	**2783.73**	**10.66**	
Bus	Facilities	18.15	$1.34	7.37
	Subtotal	**18.15**	**1.34**	
Port	Facilities	206.58	$26.43	12.79
	Subtotal	**206.58**	**26.43**	
Airport	Facilities	490.01	$44.51	9.08
	Runways	3,415.38	$0.00	0.00
	Subtotal	**3905.39**	**44.51**	
	Total	**30469.65**	**187.62**	

Table 46: Transportation System Economic Loss, Accounting for Local Site Effects (Millions of Dollars)

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Highway	Segments	19,436.25	$0.00	0.00
	Bridges	4,117.78	$129.47	3.14
	Subtotal	**23554.03**	**129.47**	
Railways	Segments	2,631.05	$0.00	0.00
	Bridges	19.59	$0.37	1.89
	Facilities	133.09	$12.79	9.61
	Subtotal	**2783.73**	**13.16**	
Bus	Facilities	18.15	$1.11	6.12
	Subtotal	**18.15**	**1.11**	
Port	Facilities	206.58	$29.13	14.10
	Subtotal	**206.58**	**29.13**	
Airport	Facilities	490.01	$34.80	7.10
	Runways	3,415.38	$0.00	0.00
	Subtotal	**3905.39**	**34.80**	
	Total	**30469.65**	**207.67**	

5.2.4.3 Utility Systems

The economic losses to the utility lifeline systems are shown in Tables 47 and 48. The estimated economic losses decreased when site class effects were added for all utility systems except the natural gas system. The total economic losses to the utility system decreased by approximately 17%.

Table 47: Utility System Economic Loss, Uniform Site Class D (Millions of Dollars)

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Potable Water	Pipelines	0.00	$0.00	0.00
	Facilities	1,848.15	$81.96	4.43
	Distribution	1,147.26	$27.73	2.42
	Subtotal	**2,995.41**	**$109.69**	
Waste Water	Pipelines	0.00	$0.00	0.00
	Facilities	17,224.76	$851.18	4.94
	Distribution	688.36	$21.93	3.19
	Subtotal	**17,913.11**	**$873.11**	
Natural Gas	Pipelines	0.00	$0.00	0.00
	Facilities	16.94	$0.97	5.72
	Distribution	458.90	$23.45	5.11
	Subtotal	**475.84**	**$24.42**	
Electrical Power	Facilities	2,686.20	$96.18	3.58
	Subtotal	**2,686.20**	**$96.18**	
Communication	Facilities	10.99	$0.50	4.52
	Subtotal	**10.99**	**$0.50**	
	Total	**24,082.89**	**$1,103.90**	

Table 48: Utility System Economic Loss, Accounting for Local Site Effects (Millions of Dollars)

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Potable Water	Pipelines	0.00	$0.00	0.00
	Facilities	1,848.15	$58.28	3.15
	Distribution	1,147.26	$29.82	2.60
	Subtotal	**2,995.41**	**$88.10**	
Waste Water	Pipelines	0.00	$0.00	0.00
	Facilities	17,224.76	$683.19	3.97
	Distribution	688.36	$23.59	3.43
	Subtotal	**17,913.11**	**$706.77**	
Natural Gas	Pipelines	0.00	$0.00	0.00
	Facilities	16.94	$0.81	4.76
	Distribution	458.90	$25.21	5.49
	Subtotal	**475.84**	**$26.02**	
Electrical Power	Facilities	2,686.20	$93.59	3.48
	Subtotal	**2,686.20**	**$93.59**	
Communication	Facilities	10.99	$0.41	3.71
	Subtotal	**10.99**	**$0.41**	
	Total	**24,082.89**	**$914.91**	

5.3 Site Class Effects for Massac County

The damage and loss estimates for the southern portion of Illinois decreased in general because the majority of the ground motion decreased when local site class effects were included. A study of site class effects was performed on Massac County because the local site effects did not cause a decrease in ground motion in any census tract in the county. The inclusion of site class factors caused the ground motion to increase in three out of the four census tracts in the county. The ground motion remained the same in the third census tract. The study of Massac County illustrates that when the site class effects increase the ground motion parameters, the estimated damage and losses also increase.

The size of this study region of 4 census tracts in southern Illinois is 242 square miles. According to the HAZUS general building stock inventory, there are approximately 6,000 households with over 15,000 people. The total replacement cost in the HAZUS general building stock inventory is estimated to be approximately $762 million for approximately 5,000 total buildings. A majority (84%) of the general building stock is residential housing. The total value of the transportation systems and the utility systems are $7.3 billion and $4.2 billion, respectively.

The HAZUS inventory of Essential Facilities contains 1 hospital, 10 schools, 3 fire stations, and 3 police stations.

5.3.1 Ground Motion

The ground motion program discussed in the Hazard Definition chapter of this report was used to calculate the PGA, PGV, S_a at 0.3 second, and S_a at 1.0 second for each census tract in the study region. This was done for both Massac County with the local site classes and for the county with a uniform site class D because HAZUS assumes a uniform site class D for the entire study region as a default if no site class maps are provided. The ground motion maps (PGA, PGV, S_a at 0.3 second, and S_a at

1.0 second) for the study region with a uniform site class D are shown in Figures 79 , 80, 81, and 82, respectively.

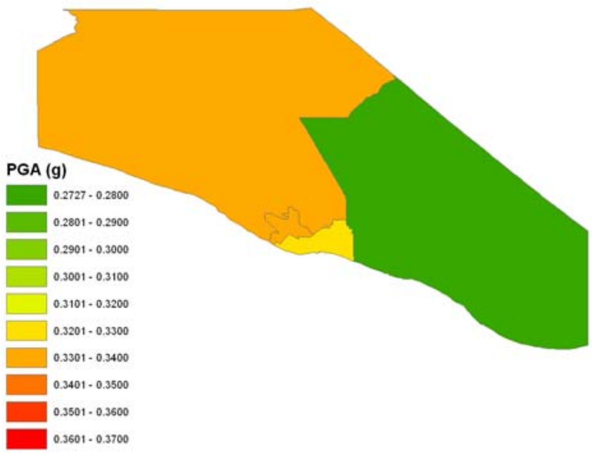


Figure 79: Massac County PGA, Uniform Soil Type D

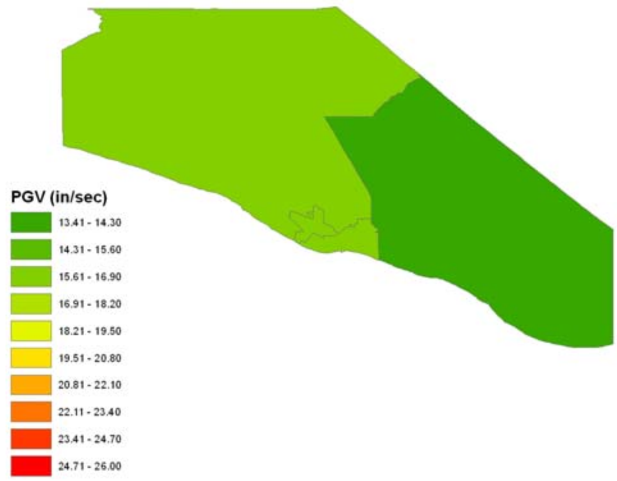


Figure 80: Massac County PGV, Uniform Soil Type D

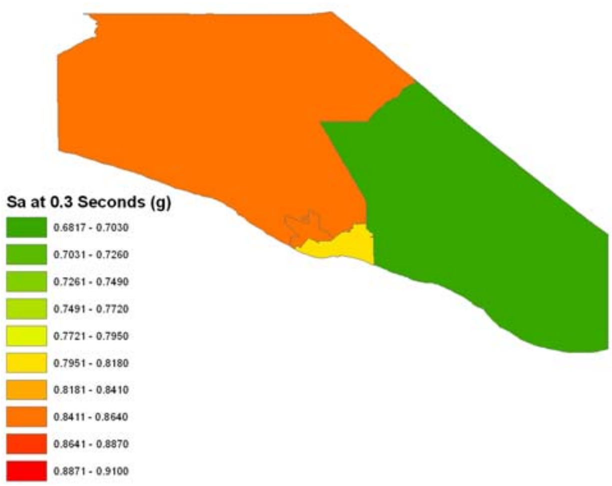


Figure 81: Massac County Sa at 0.3 Second, Uniform Soil Type D

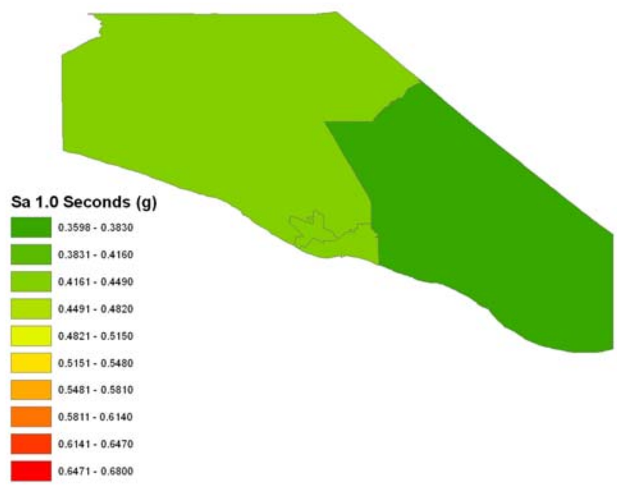


Figure 82: Massac County Sa at 1.0 Second, Uniform Soil Type D

The ground motion was computed for the same study region using the local site classes provided by ISGS. The resulting ground motion maps are shown in Figures 83, 84, 85, and 86 for PGA, PGV, S_a at 0.3 second, and S_a at 1.0 second, respectively.

Figure 83: Massac County PGA, Accounting for Site Effects

Figure 84: Massac County PGV, Accounting for Site Effects

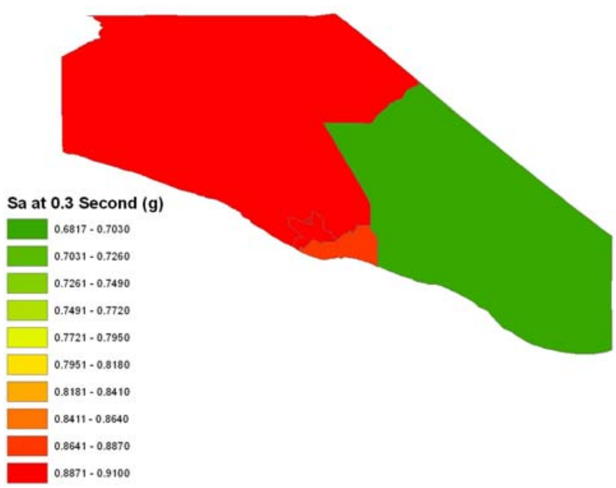


Figure 85: Massac County Sa at 0.3 Second, Accounting for Site Effects

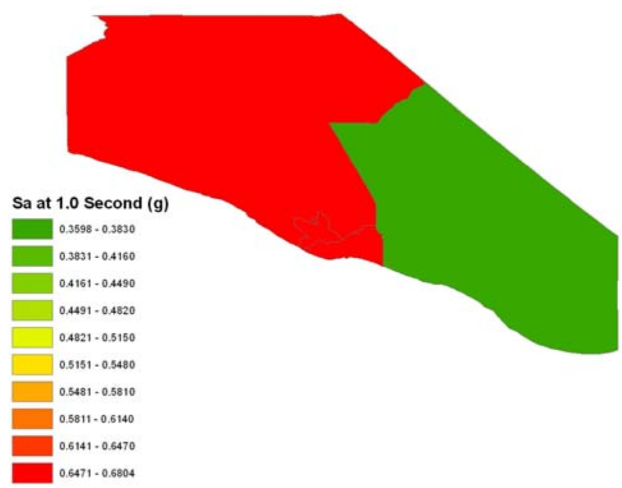


Figure 86: Massac County Sa at 1.0 Second, Accounting for Site Effects

The ground motions for the census tracts in Massac County with a uniform site class D, the ISGS site classes, and their percent differences are tabulated in Table 49. The ground motion parameters increased for all but one census tract, so the damage and loss estimates were expected to increase.

Table 49: Ground Motion Comparison

Site Class D				
Census Tract	**PGA (g)**	**PGV (in/sec)**	**Sa at 0.3 sec (g)**	**Sa at 1.0 sec (g)**
17127970100	0.337	16.278	0.843	0.437
17127970200	0.338	16.323	0.846	0.438
17127970300	0.273	13.409	0.682	0.36
17127970400	0.325	15.702	0.812	0.421
Accounting for Local Site Effects				
Census Tract	**PGA (g)**	**PGV (in/sec)**	**Sa at 0.3 sec (g)**	**Sa at 1.0 sec (g)**
17127970100	0.361	25.292	0.903	0.679
17127970200	0.362	25.359	0.905	0.68
17127970300	0.273	13.409	0.682	0.36
17127970400	0.351	24.413	0.877	0.655
Percent Difference				
Census Tract	**PGA**	**PGV**	**Sa at 0.3 sec**	**Sa at 1.0 sec**
17127970100	7.12%	55.38%	7.12%	55.38%
17127970200	7.10%	55.36%	6.97%	55.25%
17127970300	0.00%	0.00%	0.00%	0.00%
17127970400	8.00%	55.48%	8.00%	55.58%

5.3.2 Damage Estimates

The damage estimates from HAZUS for the case with a uniform site class D and the case including the local site effects on the ground motion are compared in this section.

5.3.2.1 General Building Stock

The damage estimates for the general building stock are summarized in Tables 50 and 51 for the HAZUS analyses excluding and including site class effects, respectively. The number of buildings that suffered complete damage more than doubled when the effects of local site conditions were considered. The number of buildings that were extensively damaged, moderately damaged, slightly damaged, and undamaged decreased when the local site effects were considered. The number of buildings expected to be in the less severe damage states reduced because many moved up to the complete damage state when site factors were included.

Table 50: Damage by Occupancy, Uniform Site Class D

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Agriculture	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Commercial	0	0.03	1	0.08	9	0.41	12	1.03	9	1.38
Education	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Government	0	0.00	0	0.01	1	0.03	1	0.11	1	0.15
Industrial	0	0.00	0	0.01	1	0.03	2	0.14	2	0.23
Other Residential	3	1.53	50	3.51	327	15.66	614	52.12	389	59.27
Religion	0	0.02	1	0.04	1	0.05	1	0.11	1	0.16
Single Family	207	98.41	1,370	96.37	1,752	83.81	548	46.49	255	38.81
Total	**210**		**1,422**		**2,091**		**1,179**		**656**	

Table 51: Building Damage by Occupancy, Accounting for Local Site Effects

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Agriculture	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Commercial	0	0.00	0	0.01	2	0.11	8	0.86	21	1.56
Education	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Government	0	0.00	0	0.00	0	0.01	1	0.07	2	0.17
Industrial	0	0.00	0	0.00	0	0.01	1	0.07	3	0.24
Other Residential	2	1.18	30	2.50	186	9.51	448	48.18	719	54.27
Religion	0	0.01	0	0.03	1	0.04	1	0.06	2	0.17
Single Family	164	98.80	1,150	97.46	1,769	90.33	472	50.75	577	43.58
Total	**166**		**1,180**		**1,959**		**929**		**1,324**	

5.3.2.2 Essential Facilities

In the case that local site effects were considered, the number of essential facilities expected to suffer at least moderate damage did not change—all of the essential facilities in Massac County were estimated to suffer at least moderate damage. However, 9 more schools, 2 more police stations, and 2 more fire stations were estimated to be completely damaged. The expected damage to essential facilities is summarized in Tables 52 and 53 for the uniform site class D and for the local site effects, respectively.

Table 52: Damage to Essential Facilities, Uniform Site Class D

Classification	Total # of Facilities	With at Least Moderate Damage		With Complete Damage		With Functionality > 50% on day 1	
		Count	%	Count	%	Count	%
Hospitals	1	1	100.0	1	100.0	0	0.0
Schools	10	10	100.0	0	0.0	0	0.0
PoliceStations	3	3	100.0	0	0.0	0	0.0
FireStations	3	3	100.0	0	0.0	0	0.0

Table 53: Damage to Essential Facilities, Accounting for Local Site Effects

Classification	Total # of Facilities	With at Least Moderate Damage		With Complete Damage		With Functionality > 50% on day 1	
		Count	%	Count	%	Count	%
Hospitals	1	1	100.0	1	100.0	0	0.0
Schools	10	10	100.0	9	90.0	0	0.0
PoliceStations	3	3	100.0	2	66.7	0	0.0
FireStations	3	3	100.0	2	66.7	0	0.0

5.3.2.3 Transportation Systems

The number of highway bridges expected to suffer moderate damage and complete damage increased by 5 bridges and 1 bridge, respectively, when local site effects were considered. The number of railway bridges and facilities expected to be at least moderately damaged increased from zero to 2 when site class effects were added. Tables 54 and 55 summarize the expected damage to the transportation system lifelines for the case in which site classes are not considered and the case in which site classes are considered, respectively.

Table 54: Damage to Transportation Systems, Uniform Site Class D

System	Component	Locations/ Segments	With at Least Mod. Damage		With Complete Damage		With Functionality > 50 % After Day 1		After Day 7	
			Count	%	Count	%	Count	%	Count	%
Highway	Segments	18	0	0.0	0	0.0	18	100.0	18	100.0
	Bridges	118	4	3.4	0	0.0	114	96.6	117	99.2
Railways	Segments	56	0	0.0	0	0.0	56	100.0	56	100.0
	Bridges	7	0	0.0	0	0.0	7	100.0	7	100.0
	Facilities	2	0	0.0	0	0.0	2	100.0	2	100.0
Port	Facilities	5	0	0.0	0	0.0	5	100.0	5	100.0
Airport	Facilities	1	0	0.0	0	0.0	1	100.0	1	100.0
	Runways	1	0	0.0	0	0.0	1	100.0	1	100.0

Table 55: Damage to Transportation Systems, Accounting for Local Site Effects

System	Component	Locations/ Segments	With at Least Mod. Damage		With Complete Damage		With Functionality > 50 % After Day 1		With Functionality > 50 % After Day 7	
			Count	%	Count	%	Count	%	Count	%
Highway	Segments	18	0	0.0	0	0.0	18	100.0	18	100.0
	Bridges	118	9	7.6	1	0.8	110	93.2	112	94.9
Railways	Segments	56	0	0.0	0	0.0	56	100.0	56	100.0
	Bridges	7	0	0.0	0	0.0	7	100.0	7	100.0
	Facilities	2	2	100.0	0	0.0	2	100.0	2	100.0
Port	Facilities	5	0	0.0	0	0.0	5	100.0	5	100.0
Airport	Facilities	1	0	0.0	0	0.0	1	100.0	1	100.0
	Runways	1	0	0.0	0	0.0	1	100.0	1	100.0

5.3.2.4 Utility Systems

Tables 56 and 57 show the expected utility system damage when a uniform site class D was assumed and when local site effects were considered. The number of all types of utility facilities that are expected to be at least moderately damaged due to the scenario event remained the same when local site effects were added.

Table 56: Damage to Utility System Facilities, Uniform Site Class D

System	Total # of Facilities	With at Least Moderate Damage		With Complete Damage		with Functionality > 50 % After Day 1		with Functionality > 50 % After Day 7	
		Count	%	Count	%	Count	%	Count	%
Waste Water	4	3	75.0	0	0.0	0	0.0	4	100.0
Natural Gas	2	2	100.0	0	0.0	0	0.0	2	100.0
Electrical Power	1	1	100.0	0	0.0	0	0.0	1	100.0
Communication	4	2	50.0	0	0.0	4	100.0	4	100.0

Table 57: Damage to Utility System Facilities, Accounting for Local Site Effects

System	Total # of Facilities	With at Least Moderate Damage		With Complete Damage		with Functionality > 50 %			
						After Day 1		After Day 7	
		Count	%	Count	%	Count	%	Count	%
Waste Water	4	3	75.0	0	0.0	0	0.0	4	100.0
Natural Gas	2	2	100.0	0	0.0	0	0.0	2	100.0
Electrical Power	1	1	100.0	0	0.0	0	0.0	1	100.0
Communication	4	2	50.0	0	0.0	4	100.0	4	100.0

The expected utility system pipeline damage is shown in Tables 58 and 59 for the cases in which site class D is assumed for the entire region and the local site effects are considered. The number of expected leaks and breaks increased for all types of utility systems containing pipelines.

Table 58: Utility System Pipeline Damage, Uniform Site Class D

System	Total Pipelines Length (kms)	Number of Leaks	Number of Breaks
Potable Water	946	378	95
Waste Water	568	299	75
Natural Gas	378	320	80

Table 59: Utility System Pipeline Damage, Accounting for Local Site Effects

System	Total Pipelines Length (kms)	Number of Leaks	Number of Breaks
Potable Water	946	854	213
Waste Water	568	675	169
Natural Gas	378	722	180

The number of households without potable water and electric power one day, three days, seven days, 30 days, and 90 days after the earthquake are shown in Tables 60 and 61. The number of households without potable water on the day of the earthquake increases by approximately 120%, and the number of households estimated to be without electric power decreases by about 4% when the effects of local soil conditions are considered.

Table 60: Potable Water & Electric Power System Performance, Uniform Site Class D

	Total # of Households	Households without Service									
		At Day 1		At Day 3		At Day 7		At Day 30		At Day 90	
		Count	%	Count	%	Count	%	Count	%	Count	%
Potable Water	6,261	2,244	35.8	199	3.2	0	0.0	0	0.0	0	0.0
Electric Power		3,298	52.7	1,658	26.5	446	7.1	55	0.9	5	0.1

Table 61: Potable Water and Electric Power System Performance, Accounting for Local Site Effects

	Total # of Households	Households without Service									
		At Day 1		At Day 3		At Day 7		At Day 30		At Day 90	
		Count	%	Count	%	Count	%	Count	%	Count	%
Potable Water	6,261	4,954	79.1	4,213	67.3	908	14.5	0	0.0	0	0.0
Electric Power		3,434	54.8	1,821	29.1	531	8.5	69	1.1	5	0.1

5.3.3 Social Losses

Social losses include the number of displaced households, people seeking public shelters, injuries, and casualties. The social loss estimates from HAZUS are discussed in this section.

5.3.3.1 Displaced Households

In the case that a default site class D was assumed, HAZUS estimated that 444 households will be displaced due to the scenario earthquake. From these households, 118 people were predicted to seek public shelter. When site class effects were included, HAZUS estimated that 926 households will be displaced, and from these households, 248 people will seek public shelter. The displaced households and shelter needs increased by a factor of approximately 2.1.

5.3.3.2 Injuries and Casualties

Tables 62 and 63 show the number of casualties estimated to occur by HAZUS when site class effects are ignored and when site class effects are considered, respectively. The injuries are estimated in the cases that the earthquake would occur at 2 AM, 2 PM, and 5 PM. For each earthquake occurrence time and each injury level, the estimates increase when site classes were included.

Table 62: Casualty Estimates, Uniform Site Class D

		Level 1	Level 2	Level 3	Level 4
2 AM	Commercial	1	0	0	0
	Commuting	0	0	0	0
	Educational	0	0	0	0
	Hotels	3	1	0	0
	Industrial	4	1	0	0
	Other-Residential	79	19	2	3
	Single Family	134	35	5	10
	Total	**220**	**56**	**7**	**14**
2 PM	Commercial	92	26	4	7
	Commuting	0	0	0	0
	Educational	36	11	2	3
	Hotels	0	0	0	0
	Industrial	27	8	1	2
	Other-Residential	19	5	0	1
	Single Family	35	9	1	3
	Total	**209**	**59**	**9**	**17**
5 PM	Commercial	83	23	4	7
	Commuting	1	1	2	0
	Educational	2	1	0	0
	Hotels	1	0	0	0
	Industrial	17	5	1	1
	Other-Residential	29	7	1	1
	Single Family	54	14	2	4
	Total	**186**	**52**	**9**	**14**

Table 63: Casualty Estimates, Accounting for Local Site Effects

		Level 1	Level 2	Level 3	Level 4
2 AM	Commercial	2	1	0	0
	Commuting	0	0	0	0
	Educational	0	0	0	0
	Hotels	5	2	0	1
	Industrial	7	2	0	1
	Other-Residential	133	36	4	7
	Single Family	246	73	11	23
	Total	**393**	**113**	**16**	**31**
2 PM	Commercial	167	51	8	15
	Commuting	0	0	0	0
	Educational	74	24	4	8
	Hotels	1	0	0	0
	Industrial	52	17	3	5
	Other-Residential	33	9	1	2
	Single Family	65	20	3	6
	Total	**392**	**121**	**19**	**37**
5 PM	Commercial	152	47	7	14
	Commuting	2	4	6	1
	Educational	4	1	0	0
	Hotels	2	0	0	0
	Industrial	32	10	2	3
	Other-Residential	49	13	1	3
	Single Family	99	30	5	9
	Total	**341**	**107**	**22**	**31**

5.3.4 Economic Loss Estimates

The loss estimates for the general building stock, essential facilities, transportation systems, and utility systems are discussed in the following sections.

5.3.4.1 General Building Stock

The building related economic losses are shown in Tables 64 and 65 for each scenario. The building-related economic losses increased when the site classes were considered in the ground motion estimates for each type of building related loss and each general occupancy class. The total building-related economic losses were estimated to be 57% larger when site effects were included.

Table 64: Building-Related Economic Losses, Uniform Site Class D (Millions of Dollars)

Category	Area	Single Family	Other Residential	Commercial	Industrial	Others	Total
Income Loses							
	Wage	0.00	0.61	6.01	0.29	0.47	7.38
	Capital-Related	0.00	0.26	6.14	0.17	0.16	6.74
	Rental	4.77	2.52	3.10	0.12	0.25	10.76
	Relocation	0.54	0.10	0.17	0.01	0.08	0.91
	Subtotal	**5.31**	**3.49**	**15.42**	**0.60**	**0.97**	**25.80**
Capital Stock Loses							
	Structural	21.52	9.11	8.26	2.26	2.76	43.90
	Non_Structural	65.61	29.92	21.74	7.58	6.57	131.42
	Content	14.51	5.61	8.82	4.89	2.77	36.59
	Inventory	0.00	0.00	0.35	1.12	0.08	1.56
	Subtotal	**101.64**	**44.63**	**39.17**	**15.85**	**12.18**	**213.47**
	Total	**106.95**	**48.13**	**54.59**	**16.45**	**13.15**	**239.27**

Table 65: Building-Related Economic Losses, Accounting for Local Site Effects (Millions of Dollars)

Category	Area	Single Family	Other Residential	Commercial	Industrial	Others	Total
Income Loses							
	Wage	0.00	0.82	8.87	0.40	0.65	10.73
	Capital-Related	0.00	0.35	9.16	0.24	0.23	9.98
	Rental	6.41	3.42	4.19	0.16	0.35	14.52
	Relocation	0.73	0.13	0.22	0.02	0.12	1.21
	Subtotal	**7.13**	**4.71**	**22.43**	**0.82**	**1.35**	**36.44**
Capital Stock Loses							
	Structural	29.89	13.14	12.55	3.28	4.05	62.92
	Non_Structural	97.38	47.23	39.79	14.07	11.72	210.20
	Content	21.45	9.85	17.44	9.29	5.33	63.37
	Inventory	0.00	0.00	0.68	2.11	0.15	2.94
	Subtotal	**148.73**	**70.23**	**70.47**	**28.76**	**21.25**	**339.44**
	Total	**155.86**	**74.94**	**92.90**	**29.58**	**22.59**	**375.88**

5.3.4.2 Transportation Systems

The economic losses to the transportation system are shown in Tables 66 and 67. The economic losses increased for each type of transportation system when the site class effects were included in the analysis. The total estimated economic loss to the transportation system nearly doubled, and the losses to the highway system increased by a factor of almost 2.4.

Table 66: Transportation System Economic Loss, Uniform Site Class D (Millions of Dollars)

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Highway	Segments	472.87	$0.00	0.00
	Bridges	136.77	$13.48	9.86
	Subtotal	**609.64**	**13.48**	
Railways	Segments	63.31	$0.00	0.00
	Bridges	0.56	$0.01	2.56
	Facilities	4.84	$1.38	28.49
	Subtotal	**68.71**	**1.39**	
Port	Facilities	11.23	$3.13	27.83
	Subtotal	**11.23**	**3.13**	
Airport	Facilities	6.05	$1.71	28.34
	Runways	34.50	$0.00	0.00
	Subtotal	**40.55**	**1.71**	
	Total	**730.12**	**19.72**	

Table 67: Transportation System Economic Loss, Accounting for Local Site Effects (Millions of Dollars)

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Highway	Segments	472.87	$0.00	0.00
	Bridges	136.77	$31.76	23.22
	Subtotal	**609.64**	**31.76**	
Railways	Segments	63.31	$0.00	0.00
	Bridges	0.56	$0.06	10.12
	Facilities	4.84	$1.50	31.01
	Subtotal	**68.71**	**1.56**	
Port	Facilities	11.23	$3.40	30.27
	Subtotal	**11.23**	**3.40**	
Airport	Facilities	6.05	$1.86	30.67
	Runways	34.50	$0.00	0.00
	Subtotal	**40.55**	**1.86**	
	Total	**730.12**	**38.57**	

5.3.4.3 Utility Systems

The economic losses to the utility lifeline systems are shown in Tables 68 and 69. The estimated economic losses increased when site class effects were added for all utility systems except the natural gas system. The estimated economic loss to the utility system increased by about 16% with site class effects.

Table 68: Utility System Economic Loss, Uniform Site Class D (Millions of Dollars)

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Potable Water	Pipelines	0.00	$0.00	0.00
	Facilities	0.00	$0.00	0.00
	Distribution Lines	18.92	$1.70	8.99
	Subtotal	**18.92**	**$1.70**	
Waste Water	Pipelines	0.00	$0.00	0.00
	Facilities	295.70	$51.49	17.41
	Distribution Lines	11.35	$1.35	11.85
	Subtotal	**307.06**	**$52.83**	
Natural Gas	Pipelines	0.00	$0.00	0.00
	Facilities	2.42	$0.45	18.79
	Distribution Lines	7.57	$1.44	19.00
	Subtotal	**9.99**	**$1.89**	
Electrical Power	Facilities	122.10	$22.95	18.79
	Subtotal	**122.10**	**$22.95**	
Communication	Facilities	0.44	$0.07	15.72
	Subtotal	**0.44**	**$0.07**	
	Total	**458.52**	**$79.44**	

Table 69: Utility System Economic Loss, Accounting for Local Site Effects (Millions of Dollars)

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Potable Water	Pipelines	0.00	$0.00	0.00
	Facilities	0.00	$0.00	0.00
	Distribution Lines	18.92	$3.84	20.31
	Subtotal	**18.92**	**$3.84**	
Waste Water	Pipelines	0.00	$0.00	0.00
	Facilities	295.70	$56.20	19.00
	Distribution Lines	11.35	$3.04	26.77
	Subtotal	**307.06**	**$59.24**	
Natural Gas	Pipelines	0.00	$0.00	0.00
	Facilities	2.42	$0.51	20.92
	Distribution Lines	7.57	$3.25	42.92
	Subtotal	**9.99**	**$3.76**	
Electrical Power	Facilities	122.10	$25.54	20.92
	Subtotal	**122.10**	**$25.54**	
Communication	Facilities	0.44	$0.07	16.82
	Subtotal	**0.44**	**$0.07**	
	Total	**458.52**	**$92.45**	

5.4 Summary of Losses

5.4.1 Southern Illinois Study Region

In the large region of southern Illinois, much of the ground motion was of smaller magnitude when the site class effects were taken into account. This was because most of the study region was comprised of soil of site classes A, B, or C, which have smaller amplification coefficients in the *NEHRP Provisions* than for soil type D.

The number of buildings estimated to experience complete damage increased by about 27% when the local site classes were affected. The increase of the number completely damaged buildings took place in the census tracts with site class E, where the ground motion increased. The damage estimates for essential facilities decreased because the overall ground motion magnitudes over the entire study region decreased. In addition, very few essential facilities are located in census tracts with site class E type soil, as shown in Figure 87.

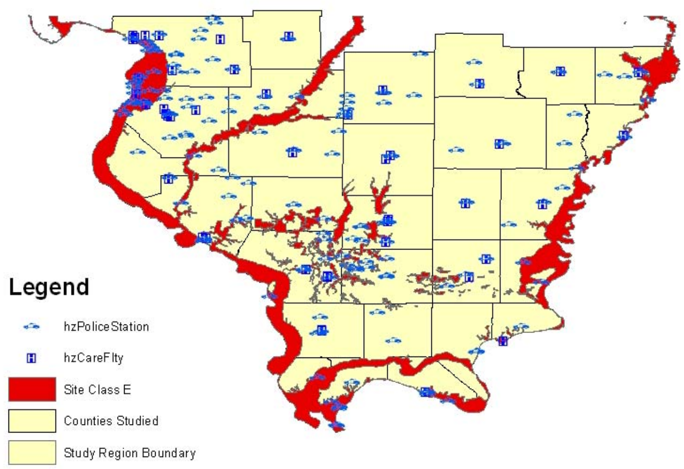


Figure 87: Locations of Essential Facilities with Respect to Site Class E Soils

The number of highway bridges expected to suffer moderate damage and complete damage both increased. The increase in damage estimates occurred in locations with site class E soils. The number of railway bridges and facilities expected to be damaged also increased with the inclusion of site class effects.

The number of utility facilities expected to be damaged either decreased or remained the same. The number of pipeline leaks and breaks increased by about 7.5% for each of the potable water, waste water, and natural gas systems. Households without potable water on the day of the earthquake increased by approximately 7%, and the number of households estimated to be without electric power decreased by about 17% when the effects of local soil conditions were included.

The number of fire ignitions, burned area, and resulting displaced people decreased when soil conditions were accounted for because the ground motion magnitude was smaller in the majority of the census tracts.

The total economic losses for the general building stock deceased by about 16% when site classes were included. The total economic losses to the transportation system increased by 10%, while the total economic losses to the utility system decreased by approximately 17%.

5.4.2 Massac County Study Region

The damage and loss estimates for the southern portion of Illinois decreased in general because the ground motion in the majority of census tracts decreased when local site class effects were included. A study was performed using Massac County because the local site effects did not cause a decrease in ground motion in any census tract in the county. The study of Massac County illustrates that when the site class effects increase the ground motion parameters, the estimated damage and losses also increase.

The ground motion was estimated to increase in three of the four census tracts in Massac County, Illinois due to the fact that they are made of soil type E. The increased ground motion caused increased damage and loss estimates in general. The number of buildings in the general building stock estimated to experience complete damage more than doubled when the effects of local site conditions were considered. The number of essential facilities expected to be completely damaged increased for schools, police stations, and fire stations.

In the transportation system, the number of highway bridges and railway bridges expected to experience moderate and complete damage both increased. The number of utility system facilities expected to be damaged remained the same when site class effects were included in the loss estimation. The leak and break estimates for the potable water, waste water, and natural gas systems became larger in magnitude when the site class effects were taken into account.

The displaced households and shelter needs increased by a factor of approximately 2.1. The injury and casualty estimates also significantly increased when soil type was included in the ground motion calculations.

The building-related economic losses were estimated to be 57% larger when site effects were included in the loss estimation. The total estimated economic loss to the transportation system nearly doubled, and the losses to the highway system increased by a factor of almost 2.4. The estimated economic loss to the utility system increased by about 16% with site class effects.

In the Massac County study region, all of the damage and loss estimates either stayed the same or increased. The results from the southern Illinois study region may mislead the reader to believe that site class effects always decrease damage estimates. The Massac County region was used illustrate that site class effects can also significantly increase damage and loss estimates.

6. Liquefaction Effects

Liquefaction maps were imported into HAZUS, and a comparison was made of the damage and loss estimates in the cases for which the effects of liquefaction were included and not included. The analysis and results are described in the following sections of this chapter.

6.1 Liquefaction Susceptibility Map

A liquefaction susceptibility map was taken from a HAZUS run that was conducted by FEMA (FEMA, 2006c). The map is shown in Figure 88. The map does not indicate real liquefaction susceptibility, but it is a site class map that was directly converted into a liquefaction map. In the development of the liquefaction susceptibility indices, soil types were directly changed into liquefaction susceptibilities. This is not a correct method to produce a liquefaction susceptibility map, so this map was used only to show the effects of imputing a liquefaction map into HAZUS. The results of this chapter should not be taken as real damage and loss results caused by liquefaction.

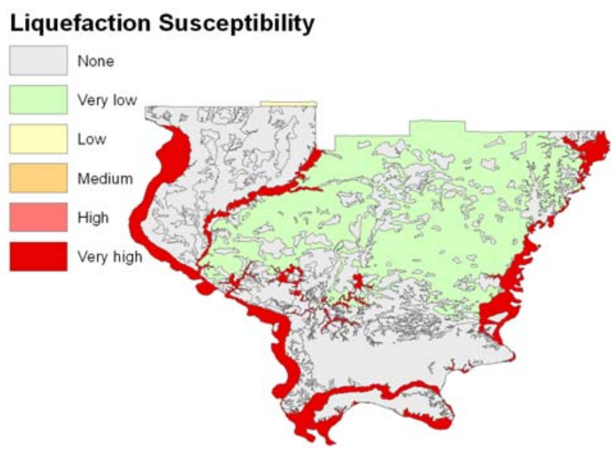


Figure 88: Liquefaction Susceptibility Map

6.2 Study Region

The liquefaction susceptibility map shown in Figure 88 was for the southern one-third of Illinois only. It completely covered 30 counties in the state of Illinois, so the study region was formed from these 30 southern counties, as shown in Figure 89.

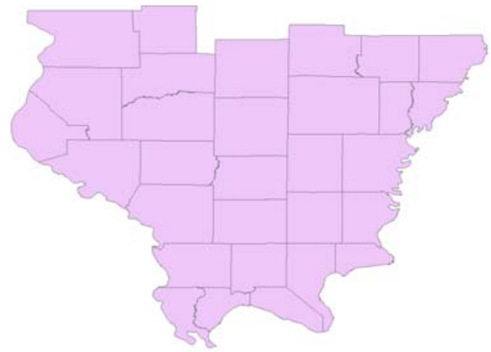


Figure 89: Counties for Analysis with Liquefaction

6.3 Ground Motion

The input ground motion was calculated using the user-supplied ground motion maps that were developed using the ground motion program as described in the Hazard Definition chapter of this report. It was assumed that the study region was of uniform soil type D for both cases in this chapter. The ground motion maps, shown in Figures 90 through 93, and the liquefaction susceptibility map were imported into HAZUS and the analysis was run. The analysis results were permanent ground deformations, damage estimates, and loss estimates, which are discussed in this chapter.

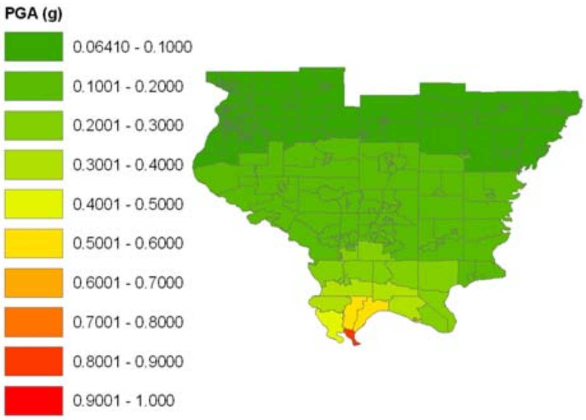


Figure 90: PGA, Uniform Soil Type D

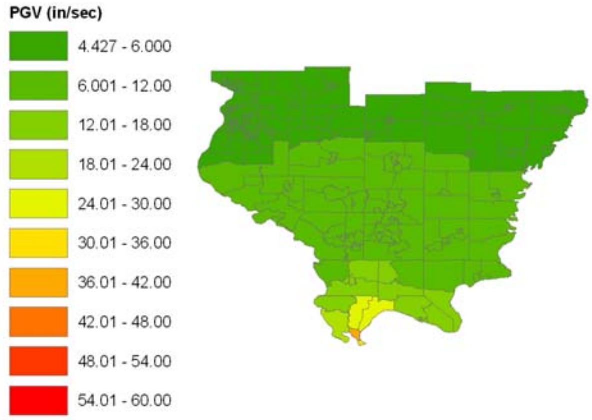


Figure 91: PGV, Uniform Soil Type D

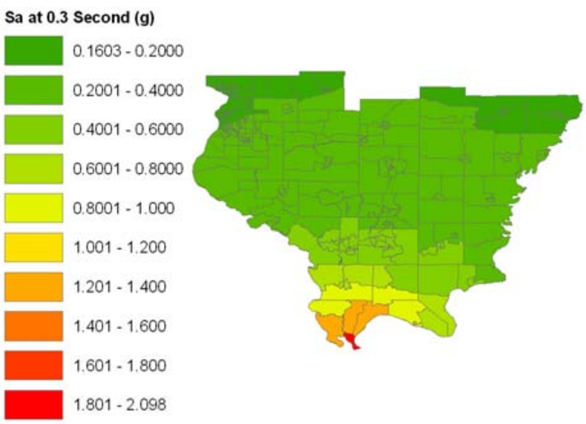


Figure 92: Sa at 0.3 Second, Uniform Soil Type D

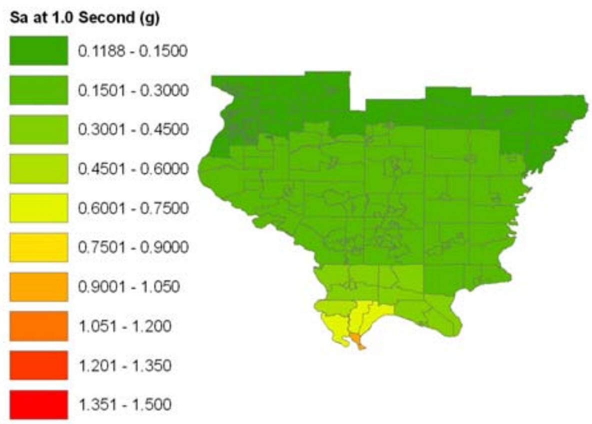


Figure 93: Sa at 1.0 Second, Uniform Soil Type D

6.4 Permanent Ground Deformation

The permanent ground deformation maps, as predicted by the PESH module in HAZUS, are shown for liquefaction spreading and liquefaction settlement in Figures 94 and 95, respectively.

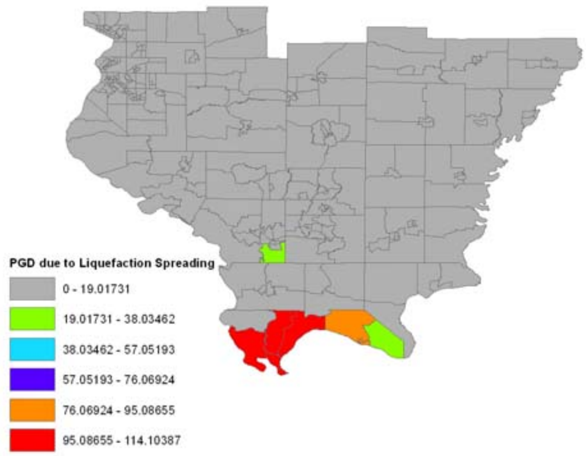


Figure 94: PGD due to Liquefaction Spreading

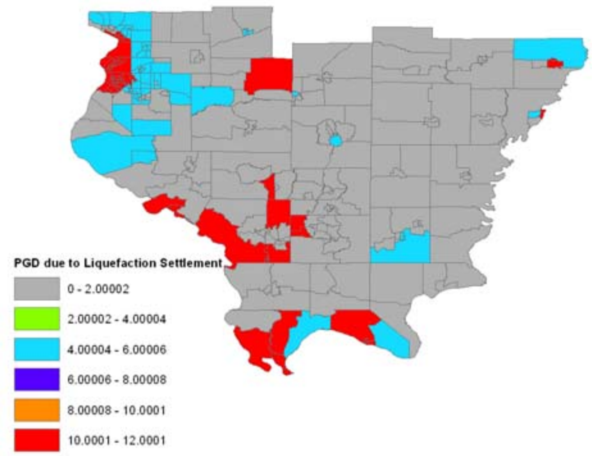


Figure 95: PGD due to Liquefaction Settlement

Twenty-two of a total 279 census tracts were estimated to have greater than zero PGD due to liquefaction spreading, and the same 227 census tracts experienced PGD due to liquefaction settlement.

The liquefaction calculations in HAZUS were checked outside of the loss estimation tool, as described in the Hazard Definition chapter of this report. The liquefaction calculations were correct for all cases, except for census tracts with" very low" liquefaction susceptibility. To correct the error, the tracts with "very low" liquefaction susceptibility were changed to have "low" liquefaction susceptibility. This change of liquefaction susceptibility slightly overestimated the PGD values from the PESH module and is conservative.

6.5 Damage Estimates

The damage estimates for the general building stock, essential facilities, transportation systems, and utility systems are discussed in the following sections.

6.5.1 General Building Stock

Tables 70 and 71 show the expected building damage by occupancy class for the study region for the cases including and not including the effects of liquefaction, respectively. The addition of liquefaction increased the number of buildings estimated to suffer extensive damage by a factor of 2.4. The number of buildings expected to suffer all other damage states reduced with the addition of liquefaction. The increase in the number of buildings suffering complete damage occurs in the census tracts estimated to have PGD. A large number of the buildings in the zones with PGD were estimated to experience complete damage.

Table 70: Expected Building Damage by Occupancy, with Liquefaction

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Agriculture	25	0.01	11	0.02	11	0.03	4	0.03	2	0.03
Commercial	1,422	0.54	586	1.20	486	1.43	167	1.49	59	0.85
Education	15	0.01	6	0.01	6	0.02	2	0.02	1	0.02
Government	77	0.03	37	0.08	35	0.10	12	0.11	6	0.09
Industrial	118	0.04	55	0.11	55	0.16	18	0.16	4	0.06
Other Residential	19,050	7.18	12,739	25.97	20,458	60.18	7,667	68.31	2,463	35.43
Religion	153	0.06	44	0.09	37	0.11	15	0.13	8	0.12
Single Family	244,363	92.13	35,568	72.52	12,908	37.97	3,339	29.75	4,408	63.41
Total	**265,224**		**49,046**		**33,996**		**11,225**		**6,952**	

Table 71: Expected Building Damage by Occupancy, without Liquefaction

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Agriculture	25	0.01	11	0.02	11	0.03	4	0.03	2	0.06
Commercial	1,424	0.54	591	1.18	495	1.40	174	1.45	37	1.29
Education	15	0.01	6	0.01	6	0.02	2	0.02	1	0.03
Government	77	0.03	37	0.07	35	0.10	12	0.10	5	0.17
Industrial	118	0.04	55	0.11	56	0.16	19	0.16	3	0.11
Other Residential	19,091	7.18	12,850	25.57	20,810	58.80	8,084	67.32	1,543	54.08
Religion	154	0.06	45	0.09	38	0.11	16	0.13	5	0.18
Single Family	245,034	92.14	36,656	72.94	13,941	39.39	3,698	30.79	1,258	44.09
Total	**265,938**		**50,252**		**35,392**		**12,008**		**2,854**	

6.5.2 Essential Facilities

The expected damage to essential facilities when liquefaction was included and the case excluding liquefaction are shown in Tables 72 and 73, respectively. The number of hospitals expected to be at least moderately damaged remained the same, while those expected to suffer at least moderate damage increased by 2 facilities when liquefaction was in included. The number of emergency operation centers, police stations, and fire stations expected to be at least moderately damage remained the same when liquefaction was included in the analysis. The number of schools, police station, and fire stations expected to suffer complete damage increased by 9 facilities, 2 facilities, and 3 facilities, respectively, when liquefaction was added.

Table 72: Expected Damage to Essential Facilities, with Liquefaction

Classification	Total # of Facilities	With at Least Moderate Damage		With Complete Damage		With Functionality > 50% on day 1	
		Count	%	Count	%	Count	%
Hospitals	45	16	35.6	1	2.2	24	53.3
Schools	587	93	15.8	18	3.1	429	73.1
EOCs	26	5	19.2	2	7.7	20	76.9
PoliceStations	154	36	23.4	8	5.2	92	59.7
FireStations	188	37	19.7	10	5.3	118	62.8

Table 73: Expected Damage to Essential Facilities, without Liquefaction

Classification	Total # of Facilities	With at Least Moderate Damage		With Complete Damage		With Functionality > 50% on day 1	
		Count	%	Count	%	Count	%
Hospitals	45	16	35.6	1	2.2	24	53.3
Schools	587	91	15.5	9	1.5	431	73.4
EOCs	26	5	19.2	2	7.7	20	76.9
PoliceStations	154	36	23.4	6	3.9	93	60.4
FireStations	188	37	19.7	7	3.7	119	63.3

The damage to essential facilities did not vary significantly when liquefaction was added to the analysis because many facilities were not located in a census tract that experienced severe liquefaction. To illustrate this point, Figure 96 shows the locations of essential facilities (hospitals and police stations) on a map of PGD. The map of PGD is identical to that shown in Figure 94 previously in this section.

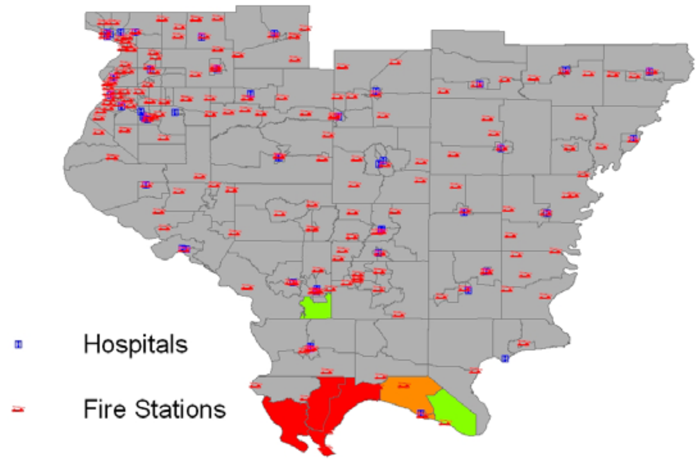


Figure 96: Hospital and Police Station Locations with Respect to PGD Due to Liquefaction Spreading

6.5.3 Transportation Systems

The expected damage to transportation systems, as estimated by HAZUS, is shown in Tables 74 and 75 for liquefaction and no liquefaction, respectively.

Table 74: Expected Damage to Transportation Systems, with Liquefaction

System	Component	Locations/ Segments	With at Least Mod. Damage		With Complete Damage		With Functionality > 50 % After Day 1		With Functionality > 50 % After Day 7	
			Count	%	Count	%	Count	%	Count	%
Highway	Segments	816	0	0.0	0	0.0	807	98.9	807	98.9
	Bridges	4,810	109	2.3	20	0.4	4,709	97.9	4,746	98.7
Railways	Segments	1,658	0	0.0	0	0.0	1,658	100.0	1,658	100.0
	Bridges	163	5	3.1	0	0.0	158	96.9	158	96.9
	Facilities	55	5	9.1	0	0.0	52	94.5	54	98.2
Bus	Facilities	15	0	0.0	0	0.0	15	100.0	15	100.0
Port	Facilities	92	11	12.0	0	0.0	81	88.0	86	93.5
Airport	Facilities	81	3	3.7	0	0.0	79	97.5	80	98.8
	Runways	99	0	0.0	0	0.0	99	100.0	99	100.0

Table 75: Expected Damage to Transportation Systems, without Liquefaction

System	Component	Locations/ Segments	With at Least Mod. Damage		With Complete Damage		With Functionality > 50 % After Day 1		With Functionality > 50 % After Day 7	
			Count	%	Count	%	Count	%	Count	%
Highway	Segments	816	0	0.0	0	0.0	807	98.9	807	98.9
	Bridges	4,810	66	1.4	6	0.1	4,750	98.8	4,769	99.1
Railways	Segments	1,658	0	0.0	0	0.0	1,658	100.0	1,658	100.0
	Bridges	163	0	0.0	0	0.0	163	100.0	163	100.0
	Facilities	55	3	5.5	0	0.0	52	94.5	55	100.0
Bus	Facilities	15	0	0.0	0	0.0	15	100.0	15	100.0
Port	Facilities	92	11	12.0	0	0.0	81	88.0	88	95.7
Airport	Facilities	81	2	2.5	0	0.0	80	98.8	80	98.8
	Runways	99	0	0.0	0	0.0	99	100.0	99	100.0

In both cases HAZUS predicted that no highway segments suffer moderate damage, however, this does not mean that there was no damage predicted for highway segments when liquefaction was included. Figure 97 shows a map of the probability of highway segments reaching at least moderate damage in the case that liquefaction was included.

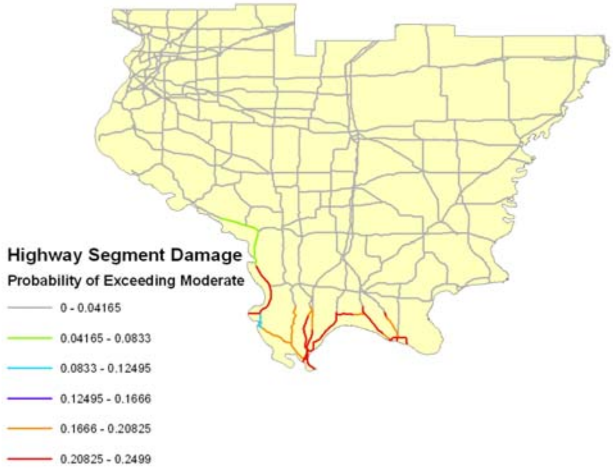


Figure 97: Highway Segment Damage, Probability of Exceeding Moderate, with Liquefaction

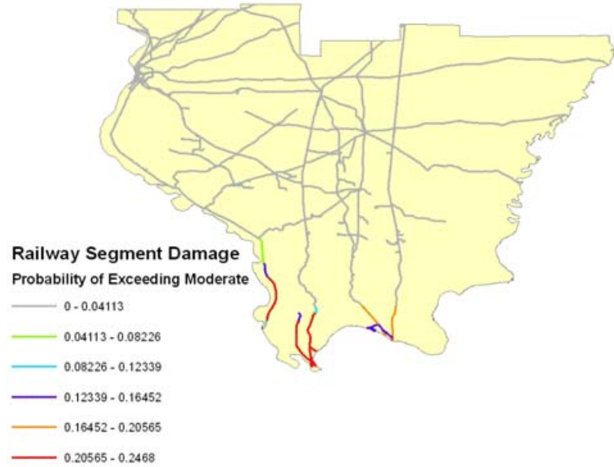


Figure 98: Railway Segment Damage, Probability of Exceeding Moderate, with Liquefaction

Similarly, in Table 74, the expected number of railway segments to suffer at least moderate damage is zero. Once again, this does not mean that no damage was predicted for railway segments. Figure 98 shows a map of the probability of exceeding moderate damage for the railway segments in the study region. The probabilities were so low that no segment was expected to suffer at least moderate damage, hence the estimate of zero in Table 84. For the case in which liquefaction was not included, the probability of damage to all highway segments is not calculated because highway segment damage is a function of PGD.

6.5.4 Utility Systems

The expected damage to the utility system facilities is shown in Tables 76 and 77 for the cases with and without liquefaction, respectively. The number of facilities in all utility systems expected to experience at least moderate damage did not change when liquefaction was added to the analysis. The scenario without liquefaction had slightly higher estimates of waste water facility functionality.

Table 76: Expected Damage to Utility Systems, with Liquefaction

System	Total	With at Least Moderate Damage		With Complete Damage		with Functionality > 50 %			
						After Day 1		After Day 7	
	# of Facilities	Count	%	Count	%	Count	%	Count	%
Potable Water	50	5	10.0	0	0.0	44	88.0	50	100.0
Waste Water	233	17	7.3	0	0.0	202	86.7	225	96.6
Natural Gas	14	3	21.4	0	0.0	11	78.6	14	100.0
Oil Systems	12	0	0.0	0	0.0	12	100.0	12	100.0
Electrical Power	22	2	9.1	0	0.0	20	90.9	22	100.0
Communication	99	6	6.1	0	0.0	98	99.0	98	99.0

Table 77: Expected Damage to Utility Systems, without Liquefaction

System	Total	With at Least Moderate Damage		With Complete Damage		with Functionality > 50 %			
						After Day 1		After Day 7	
	# of Facilities	Count	%	Count	%	Count	%	Count	%
Potable Water	50	5	10.0	0	0.0	44	88.0	50	100.0
Waste Water	233	17	7.3	0	0.0	204	87.6	231	99.1
Natural Gas	14	3	21.4	0	0.0	11	78.6	14	100.0
Oil Systems	12	0	0.0	0	0.0	12	100.0	12	100.0
Electrical Power	22	2	9.1	0	0.0	20	90.9	22	100.0
Communication	99	6	6.1	0	0.0	98	99.0	99	100.0

The damage to utility systems facilities did not vary significantly when liquefaction was added to the analysis because many facilities were not located in a census tract that experienced severe liquefaction. To illustrate this point, Figure 99 shows the locations of utility system facilities (potable water, waste water, oil, natural gas, and electric power) with a map of PGD. The map of PGD is identical to that shown in Figure 94 previously in this chapter.

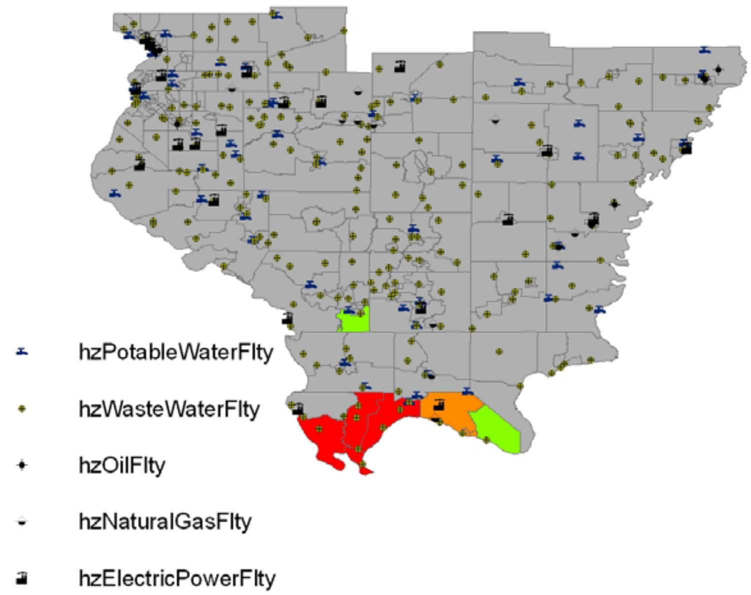


Figure 99: Utility System Facility Locations with Respect to PGD Due to Liquefaction Spreading

Tables 78 and 79 summarize the expected utility system performance for the potable water, waste water, and natural gas lifeline systems. The performance estimates include the number of leaks and breaks within each utility system. The number of leaks is significantly decreased, and the number of breaks more than doubled when liquefaction is included in the analysis. These results are expected because the number of breaks is a function of PGD (which increases from zero when liquefaction is included) in HAZUS.

Table 78: Expected Utility System Performance, with Liquefaction

System	Total Pipelines Length (kms)	Number of Leaks	Number of Breaks
Potable Water	57,363	2760	3335
Waste Water	34,418	2183	2638
Natural Gas	22,945	2333	2820

Table 79: Expected Utility System Performance, without Liquefaction

System	Total Pipelines Length (kms)	Number of Leaks	Number of Breaks
Potable Water	57,363	6163	1541
Waste Water	34,418	4874	1219
Natural Gas	22,945	5210	1303

The potable water and electric power system performance for the case in which liquefaction was included and the case in which liquefaction was not included is shown in Tables 80 and 81, respectively. The number of households without potable water significantly increased when liquefaction was included in the analysis. The reduced potable water service is largely due to the fact that pipelines are more severely damaged (i.e., suffer many more breaks) when liquefaction is included in the analysis.

There is no damage in the electric power system that is analogous to the pipeline damage in the potable water systems. HAZUS does not have the capability of calculating damage to electric power distribution lines, so the performance of the electric power systems depends only on the damage to the electric power facilities.

Table 80: Expected Potable Water and Electric Power System Performance, with Liquefaction

		Households without Service									
	Total # of Households	At Day 1		At Day 3		At Day 7		At Day 30		At Day 90	
		Count	%	Count	%	Count	%	Count	%	Count	%
Potable Water	438,310	32,215	7.3	27,959	6.4	23,766	5.4	5,327	1.2	0	0.0
Electric Power		11,049	2.5	7,235	1.7	3,736	0.9	1,248	0.3	15	0.0

Table 81: Expected Potable Water and Electric Power System Performance, without Liquefaction

	Total # of Households	Households without Service									
		At Day 1		At Day 3		At Day 7		At Day 30		At Day 90	
		Count	%	Count	%	Count	%	Count	%	Count	%
Potable Water	438,310	13,138	3.0	5,834	1.3	1,757	0.4	0	0.0	0	0.0
Electric Power		10,754	2.5	6,474	1.5	2,540	0.6	495	0.1	15	0.0

6.5.6 Fire Following Earthquake

The Fire Following Earthquake (FFE) model in HAZUS estimated that there would be 17 ignitions that would burn about 0.10 square mile of area due to the scenario earthquake in the case that liquefaction was included in the analysis. In the case that liquefaction was not included, the same number of ignitions and burned area was estimated. The number of ignitions is a function of building square footage and ground motion. Because the building stock inventory and the ground motion parameters remained the same, the FFE estimates remained the same when liquefaction was included.

6.6 Social Losses

Social losses include the number of displaced households, people seeking public shelters, injuries, and casualties. The social loss estimates from HAZUS are discussed in this section.

6.6.1 Displaced Households

HAZUS estimated that 7,662 households would be displaced by the scenario earthquake when liquefaction was included in the analysis. Of the displaced households, 2,136 people were estimated to seek temporary shelter in public shelters. In the case that liquefaction was not included in the HAZUS analysis, it was estimated that 2,875 households will be displaced and of these displaced households, 859 people will seek temporary shelter in public shelters.

The number of displaced households was estimated by the damage to the general building stock and the demographic data for the study region. The demographic data is identical for the two study regions. HAZUS estimates that a factor of 2.6 more people will seek public shelter because the number of buildings expected to suffer complete damage increases by a similar factor. The number of people seeking public shelter is estimated using the demographic data in the study region, and for both regions, this estimate is about 11% of the total displaced people. Note that a household in HAZUS is assumed to comprise of 2.5 people.

6.6.2 Injuries and Casualties

The injury and casualty estimates from HAZUS are shown in Tables 82 and 83 for the study region including liquefaction and the study region not including liquefaction, respectively. The number of injuries and casualties increased at each time of earthquake occurrence when liquefaction is added to the analysis. The increase in the injury and casualty estimates were due to the increased number of completely damaged buildings when liquefaction was added to the analysis. The number of level 1 injuries was estimated to increase by 51.9%, 31.4%, and 39.8% at 2 AM, 2 PM, and 5 PM, respectively, when the effects of liquefaction were considered. The number of level 2 injuries increased by 71.6%, 45.1%, and 60.7% at the earthquake occurrence times 2 AM, 2 PM, and 5 PM, respectively. The level 3 injuries were estimated to increase by 62.2%, 51.4%, and 59% at 2 AM, 2 PM, and 5 PM, respectively. Finally, the number of casualties (level 4 injuries) were estimated to increase by 61.4%, 48.5%, and 59.1% at the earthquake occurrence times 2 AM, 2 PM, and 5 PM, respectively, when liquefaction was included in the loss estimation.

Table 82: Casualty Estimates, with Liquefaction

		Level 1	Level 2	Level 3	Level 4
2 AM	Commercial	9	2	0	1
	Commuting	0	0	0	0
	Educational	0	0	0	0
	Hotels	14	3	0	1
	Industrial	14	3	0	1
	Other-Residential	824	172	15	28
	Single Family	1,401	355	43	83
	Total	**2,262**	**537**	**60**	**113**
2 PM	Commercial	751	177	23	45
	Commuting	1	2	3	1
	Educational	290	74	11	21
	Hotels	3	1	0	0
	Industrial	100	25	3	6
	Other-Residential	180	39	4	7
	Single Family	339	88	12	21
	Total	**1,663**	**405**	**56**	**101**
5 PM	Commercial	697	169	23	43
	Commuting	22	36	53	11
	Educational	42	9	1	2
	Hotels	4	1	0	0
	Industrial	63	15	2	4
	Other-Residential	306	65	6	11
	Single Family	564	146	19	34
	Total	**1,699**	**442**	**105**	**105**

Table 83: Casualty Estimates, without Liquefaction

		Level 1	Level 2	Level 3	Level 4
2 AM	Commercial	8	2	0	0
	Commuting	0	0	0	0
	Educational	0	0	0	0
	Hotels	10	2	0	1
	Industrial	11	2	0	1
	Other-Residential	656	124	11	20
	Single Family	804	183	25	49
	Total	**1,489**	**313**	**37**	**70**
2 PM	Commercial	607	130	16	31
	Commuting	1	1	1	0
	Educational	230	53	7	14
	Hotels	2	0	0	0
	Industrial	82	18	2	4
	Other-Residential	143	28	3	5
	Single Family	202	48	7	13
	Total	**1,266**	**279**	**37**	**68**
5 PM	Commercial	551	121	15	29
	Commuting	10	13	21	4
	Educational	36	7	1	2
	Hotels	3	1	0	0
	Industrial	51	11	1	3
	Other-Residential	242	46	4	8
	Single Family	322	76	11	20
	Total	**1,215**	**275**	**54**	**66**

6.7 Direct Economic Losses

The direct economic losses to the study region considering the effects of liquefaction and the same study region ignoring the effects of liquefaction were computed using HAZUS. The losses are discussed in the following sections.

6.7.1 Building-Related

The building-related economic losses for the two studies are shown in Tables 84 and 85. The building-related economic loss estimates are higher for the study region including liquefaction for every category of loss in every occupancy class. The total building-related economic losses increased by approximately 33% when liquefaction was included. The increase in losses was expected because the number of buildings that were estimated to experience complete damage increased by more than a factor of two.

Table 84: Building-Related Economic Losses (Millions of Dollars), with Liquefaction

Category	Area	Single Family	Other Residential	Commercial	Industrial	Others	Total
Income Loses							
	Wage	0.00	5.42	99.65	2.80	7.31	115.17
	Capital-Related	0.00	2.38	81.91	1.80	2.18	88.26
	Rental	48.55	38.94	43.75	0.96	3.45	135.64
	Relocation	5.38	1.51	2.82	0.11	1.09	10.90
	Subtotal	**53.93**	**48.24**	**228.11**	**5.66**	**14.03**	**349.97**
Capital Stock Loses							
	Structural	230.76	119.48	106.40	15.36	30.15	502.16
	Non_Structural	719.40	359.58	212.78	33.72	68.59	1,394.07
	Content	199.94	67.94	88.81	19.70	31.45	407.85
	Inventory	0.00	0.00	3.76	4.31	0.74	8.80
	Subtotal	**1,150.11**	**547.00**	**411.75**	**73.09**	**130.93**	**2,312.88**
	Total	**1,204.03**	**595.24**	**639.86**	**78.75**	**144.96**	**2,662.85**

Table 85: Building-Related Economic Losses (Millions of Dollars), without Liquefaction

Category	Area	Single Family	Other Residential	Commercial	Industrial	Others	Total
Income Loses							
	Wage	0.00	4.24	93.34	2.66	6.76	107.00
	Capital-Related	0.00	1.85	76.44	1.73	1.96	81.98
	Rental	32.54	31.35	41.65	0.93	3.15	109.62
	Relocation	3.62	1.32	2.70	0.11	0.99	8.73
	Subtotal	**36.16**	**38.76**	**214.13**	**5.43**	**12.85**	**307.33**
Capital Stock Loses							
	Structural	149.79	105.12	97.92	14.54	27.46	394.84
	Non_Structural	454.26	289.29	175.43	27.69	56.27	1,002.94
	Content	134.62	50.90	69.60	16.06	24.52	295.70
	Inventory	0.00	0.00	2.95	3.51	0.60	7.07
	Subtotal	**738.67**	**445.32**	**345.90**	**61.80**	**108.86**	**1,700.55**
	Total	**774.83**	**484.07**	**560.03**	**67.23**	**121.71**	**2,007.88**

6.7.2 Transportation Systems

The estimated economic losses to the transportation system are shown in Tables 86 and 87 for the study region including and excluding liquefaction, respectively. In every transportation system the estimated losses were higher when liquefaction was included. There was greater than zero economic loss to highway segments because damage to roadway segments were calculated. When the effects of liquefaction were ignored, no damage to roadway segments was calculated because the estimated PGD in all tracts was zero; therefore, no economic loss was associated with roadway segment damage.

Similarly, the economic losses associated with the railway transportation system and airport transportation system was higher when liquefaction was included because the damage to railway segments and runway segments was greater than zero because liquefaction was present. In addition, the direct economic loss to facilities and bridges increased with the addition of liquefaction.

Table 86: Transportation System Economic Losses (Millions of Dollars), with Liquefaction

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Highway	Segments	19,436.25	$193.04	0.99
	Bridges	4,117.78	$158.89	3.86
	Tunnels	0.00	$0.00	0.00
	Subtotal	**23554.03**	**351.93**	
Railways	Segments	2,631.05	$20.74	0.79
	Bridges	19.59	$0.42	2.13
	Tunnels	0.00	$0.00	0.00
	Facilities	133.09	$11.69	8.78
	Subtotal	**2783.73**	**32.85**	
Bus	Facilities	18.15	$1.34	7.39
	Subtotal	**18.15**	**1.34**	
Port	Facilities	206.58	$29.74	14.40
	Subtotal	**206.58**	**29.74**	
Airport	Facilities	490.01	$46.89	9.57
	Runways	3,415.38	$29.16	0.85
	Subtotal	**3905.39**	**76.05**	
	Total	**30469.65**	**491.91**	

Table 87: Transportation System Economic Losses (Millions of Dollars), without Liquefaction

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Highway	Segments	19,436.25	$0.00	0.00
	Bridges	4,117.78	$104.68	2.54
	Tunnels	0.00	$0.00	0.00
	Subtotal	**23554.03**	**104.68**	
Railways	Segments	2,631.05	$0.00	0.00
	Bridges	19.59	$0.18	0.90
	Tunnels	0.00	$0.00	0.00
	Facilities	133.09	$10.48	7.88
	Subtotal	**2783.73**	**10.66**	
Bus	Facilities	18.15	$1.34	7.37
	Subtotal	**18.15**	**1.34**	
Port	Facilities	206.58	$26.43	12.79
	Subtotal	**206.58**	**26.43**	
Airport	Facilities	490.01	$44.51	9.08
	Runways	3,415.38	$0.00	0.00
	Subtotal	**3905.39**	**44.51**	
		30469.65	**187.62**	

6.7.3 Utility Systems

The losses to the utility lifeline systems are shown in Tables 88 and 89 for the cases in which liquefaction was included and excluded, respectively. The losses to all utility systems were estimated to be greater when liquefaction was included in the analysis. The total losses to the utility system increased by approximately 16% when liquefaction was added to the analysis.

Table 88: Utility System Economic Losses (Millions of Dollars), with Liquefaction

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Potable Water	Pipelines	0.00	$0.00	0.00
	Facilities	1,848.15	$91.97	4.98
	Distribution Lines	1,147.26	$38.87	3.39
	Subtotal	**2,995.41**	**$130.84**	
Waste Water	Pipelines	0.00	$0.00	0.00
	Facilities	17,224.76	$958.43	5.56
	Distribution Lines	688.36	$30.74	4.47
	Subtotal	**17,913.11**	**$989.17**	
Natural Gas	Pipelines	0.00	$0.00	0.00
	Facilities	16.94	$1.08	6.38
	Distribution Lines	458.90	$32.86	7.16
	Subtotal	**475.84**	**$33.94**	
Oil Systems	Pipelines	0.00	$0.00	0.00
	Facilities	1.33	$0.01	0.76
	Subtotal	**1.33**	**$0.01**	
Electrical Power	Facilities	2,686.20	$131.37	4.89
	Subtotal	**2,686.20**	**$131.37**	
Communication	Facilities	10.99	$0.58	5.30
	Subtotal	**10.99**	**$0.58**	
	Total	**24,082.89**	**$1,285.91**	

Table 89: Utility System Economic Losses (Millions of Dollars), without Liquefaction

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Potable Water	Pipelines	0.00	$0.00	0.00
	Facilities	1,848.15	$81.96	4.43
	Distribution	1,147.26	$27.73	2.42
	Subtotal	**2,995.41**	**$109.69**	
Waste Water	Pipelines	0.00	$0.00	0.00
	Facilities	17,224.76	$851.18	4.94
	Distribution	688.36	$21.93	3.19
	Subtotal	**17,913.11**	**$873.11**	
Natural Gas	Pipelines	0.00	$0.00	0.00
	Facilities	16.94	$0.97	5.72
	Distribution	458.90	$23.45	5.11
	Subtotal	**475.84**	**$24.42**	
Electrical Power	Facilities	2,686.20	$96.18	3.58
	Subtotal	**2,686.20**	**$96.18**	
Communication	Facilities	10.99	$0.50	4.52
	Subtotal	**10.99**	**$0.50**	
	Total	**24,082.89**	**$1,103.90**	

6.8 Summary of Losses

The addition of the effects of liquefaction increased the number of buildings expected to experience complete damage by a factor of 2.4. The number of essential facilities expected to be at least moderately damage was not significantly affected because the majority of the essential facilities were not located in census tracts that experienced liquefaction.

Similarly, the number of utility system facilities was not significantly affected because many of the facilities were not located in regions with a high liquefaction susceptibility index. However, the number of pipeline breaks significantly increased due to the ground deformation due to liquefaction. Because the number of estimated pipeline breaks more than doubled when liquefaction was included, the number of households without potable water increased by a factor of more than 2.5.

The number of highway bridges expected to be at least moderately damaged nearly doubled when liquefaction was included in the analysis, but the other transportation system components were not significantly affected.

The number of displaced households increased by a factor of approximately 2.6 because the number of completely damage buildings more than doubled when liquefaction was included in the loss estimation. The number of injuries and casualties increased between 50% and 70%.

The total direct economic losses increased from approximately $3.3 billion to $4.44 billion for the 30 counties in the liquefaction study region. This represents a 35% increase in direct economic losses.

7. Improved Essential Facilities Inventory

An inventory of essential facilities containing data for hospitals, schools, police stations, and fire stations was collected by French and Olshansky (2000). This inventory is an improvement over the HAZUS default essential facilities inventory. The inventory is a detailed inventory for 31 counties in Illinois that is based on tax assessor's data and telephone surveys (French and Olshansky, 2000). The inventory contains more accurate building types than the HAZUS inventory, which assumes a single default building type for each essential facility class. The HAZUS essential facility inventory for the 31 counties to study in detail contains 46 hospitals, 162 police stations, 197 fire stations, and 617 schools for a total of 1022 essential facilities. The essential facilities inventory from French and Olshansky contains 152 hospitals, 185 police stations, 254 fire stations, and 965 schools for a total of 1556 essential facilities. The hospital inventory, school inventory, police station inventory, and fire station inventory are shown in Figures 100 through 103, respectively. The improved essential facilities are indicated by a large green dot (labeled the MAEC inventory in the figures), and the HAZUS default essential facilities are indicated by a small pink dot.

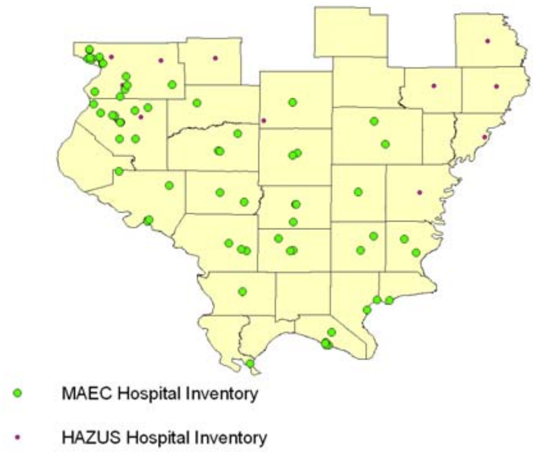


Figure 100: Hospital Inventory

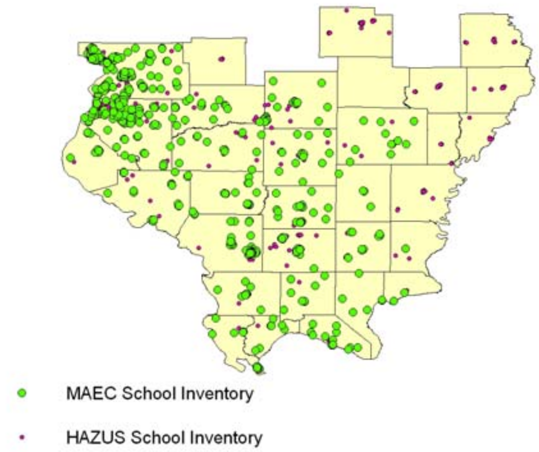


Figure 101: School Inventory

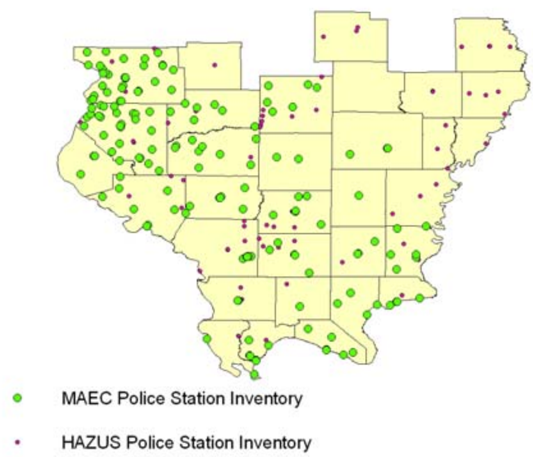


Figure 102: Police Station Inventory

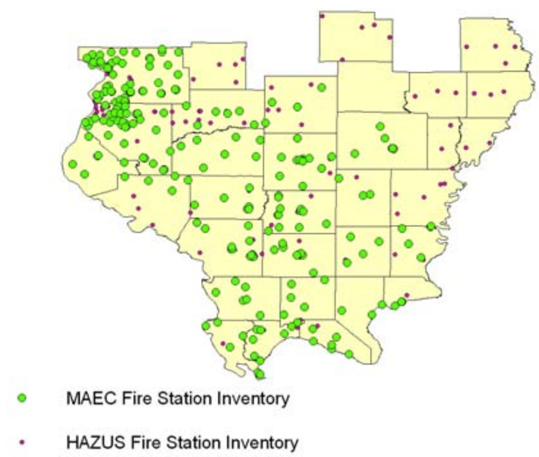


Figure 103: Fire Station Inventory

7.1 Essential Facility Inventory Classification

A sensitivity analysis was conducted to determine the parameters that affect damage estimates to essential facilities in HAZUS. It was determined that damage to essential facilities depends on the HAZUS model building type and design code level. This result is consistent with the HAZUS Technical Manual. An improved essential facilites inventory was provided by French and Olshansky (2000). Therefore, only the building types and geographical locations of essential facilities were taken from the French and Olshansky (2000) essential inventory database and used in HAZUS.

The improved essential facilities inventory was imported into HAZUS. The majority of facilities were already assigned a building type in the improved inventory. The distribution of each building type in each essential facility within the improved database was calculated. This distribution was then used to assign building types to the remaining essential facilities. The building type distribution for hospitals, schools, police stations, and fire stations are shown in Tables 90 through 93, respectively.

Table 90: Building Type Distribution used to Assign Building Types to Hospitals

Hospital Building Type Distribution		
Building Type	**Percent**	**Building Count**
W2	13.42%	20
S1L	5.37%	8
S1M	2.68%	4
S1H	0.67%	1
S2L	3.36%	5
S2M	1.34%	2
S3	2.68%	4
C1L	4.03%	6
C1H	0.67%	1
C2M	0.67%	1
C3L	7.38%	11
C3M	3.36%	5
RML	1.34%	2
URML	44.30%	67
URMM	8.72%	13
Total	100.00%	152

Table 91: Building Type Distribution used to Assign Building Types to Schools

School Building Type Distribution		
Building Type	**Percent**	**Building Count**
W2	16.65%	161
S1L	5.25%	51
S2L	2.68%	26
S3	2.68%	26
S4L	0.78%	8
S4M	0.45%	4
C1L	0.22%	2
C1M	0.22%	2
C2L	0.56%	5
C2H	0.34%	3
C3L	7.37%	71
C3M	0.89%	9
PC2L	0.11%	1
PC2M	0.11%	1
RML	1.34%	13
URML	51.96%	501
URMM	8.38%	81
Total	100.00%	965

Table 92: Building Type Distribution used to Assign Building Types to Police Stations

Police Station Building Type Distribution		
Building Type	**Percent**	**Building Count**
W2	19.16%	35
S1L	2.40%	4
S1M	0.60%	1
S2L	5.39%	10
C1L	1.20%	2
C1M	1.20%	2
C2L	1.80%	3
C3L	4.79%	9
RML	0.60%	1
URML	57.49%	106
URMM	5.39%	10
Total	100.00%	185

Table 93: Building Type Distribution used to Assign Building Types to Fire Stations

Fire Station Building Type Distribution		
Building Type	**Percent**	**Building Count**
W2	23.65%	60
S1L	2.49%	6
S2L	0.41%	1
S3	11.62%	30
C1L	0.41%	1
C2L	0.41%	1
C3L	0.83%	2
RML	0.41%	1
URML	58.51%	149
URMM	1.24%	3
Total	100.00%	254

After the building types were assigned to the essential facilities in the database, they were imported into HAZUS, and damage was estimated.

7.2 Essential Facility Damage

The damage to the new essential facilities was estimated using HAZUS once the inventory was imported into the loss estimation tool. The expected damage is shown for the MAEC essential facility inventory and the HAZUS essential facility inventory in Tables 94 and 95, respectively.

Although there were fewer hospitals in the HAZUS inventory than the improved inventory, three fewer hospitals were estimated to be at least moderately damaged when the new hospital inventory was used. The improved essential inventory contains 348 more schools than the HAZUS inventory, and 79 more hospitals were estimated be at least moderately damaged by HAZUS. HAZUS estimated that 40 police stations in the new inventory and 30 police stations in the HAZUS inventory will suffer at least moderate damage. It was estimated that 4 more fire stations would be at least moderately damaged when the improved essential facility inventory replaced the HAZUS inventory. . This difference in losses between the two databases is due to the fact that a specific building type was assigned to each essential facility in the new inventory.

Table 94: Essential Facility Damage, MAEC Inventory

Classification	Total	With at Least Moderate Damage		With Complete Damage		With Functionality > 50% on day 1	
	# of Facilities	Count	%	Count	%	Count	%
Hospitals	152	13	8.6	1	0.7	118	77.6
Schools	965	173	17.9	19	2.0	701	72.6
PoliceStations	185	30	16.2	7	3.8	126	68.1
FireStations	254	43	16.9	11	4.3	168	66.1

Table 95: Essential Facility Damage, HAZUS Inventory

Classification	Total # of Facilities	With at Least Moderate Damage		With Complete Damage		With Functionality > 50% on day 1	
		Count	%	Count	%	Count	%
Hospitals	46	16	34.8	1	2.2	24	52.2
Schools	617	94	15.2	9	1.5	451	73.1
PoliceStations	162	40	24.7	6	3.7	97	59.9
FireStations	197	39	19.8	7	3.6	124	62.9

The probability of exceeding moderate damage for hospitals in the imported inventory is mapped in Figure 104, and the functionality of hospitals at day 1 is shown in Figure 105.

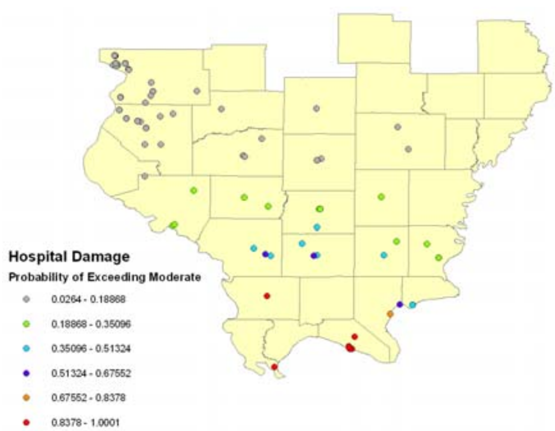


Figure 104: Probability of Exceeding Moderate Damage for Hospitals

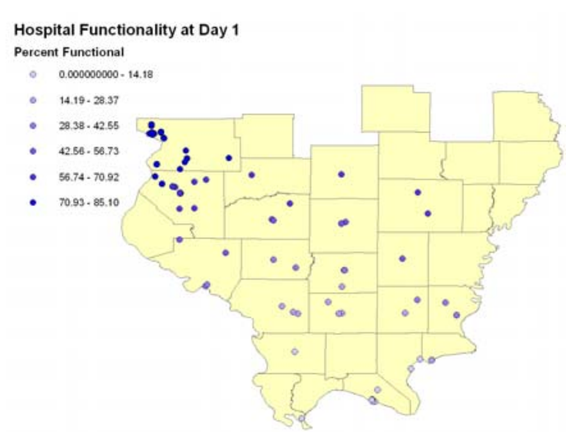


Figure 105: Hospital Functionality at Day 1

The probability of exceeding moderate damage for schools in the new inventory is mapped in Figure 106, and the functionality of schools at day 1 is shown in Figure 107.

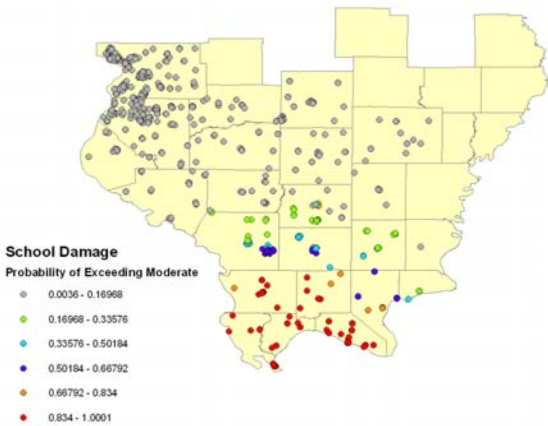


Figure 106: Probability of Exceeding Moderate Damage for Schools

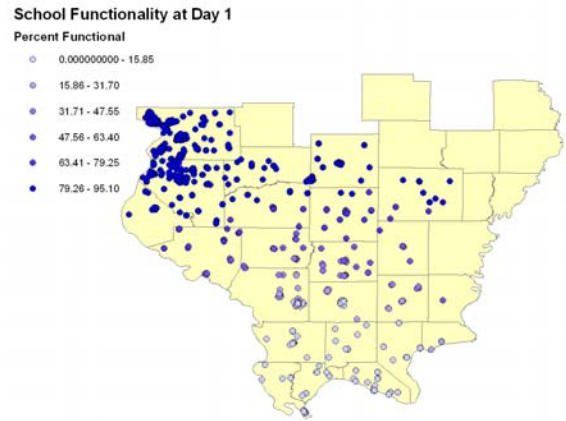


Figure 107: School Functionality at Day 1

The probability of exceeding moderate damage for police stations in the improved inventory is mapped in Figure 108, and the functionality of police stations at day 1 is shown in Figure 109.

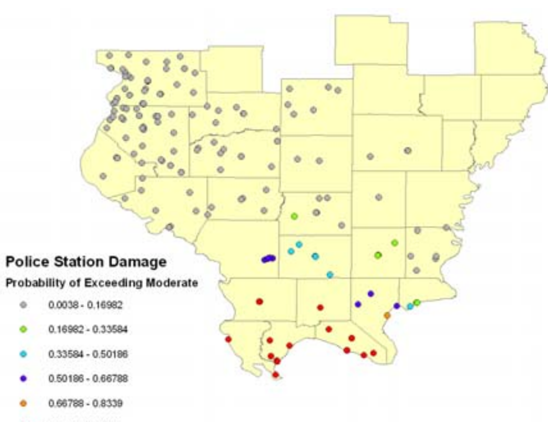


Figure 108: Probability of Exceeding Moderate Damage for Police Stations

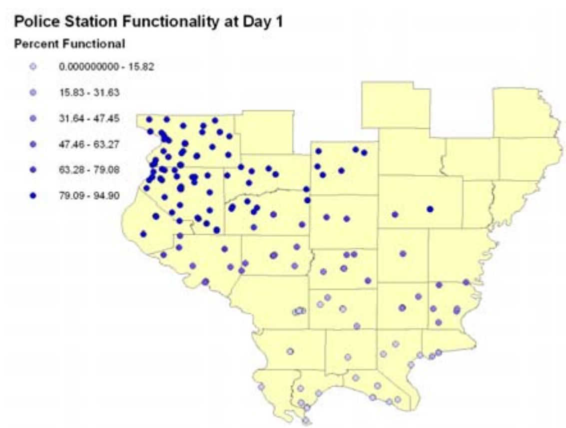


Figure 109: Police Station Functionality at Day 1

The probability of exceeding moderate damage for fire stations in the imported inventory is mapped in Figure 110, and the functionality of fire stations at day 1 is shown in Figure 111.

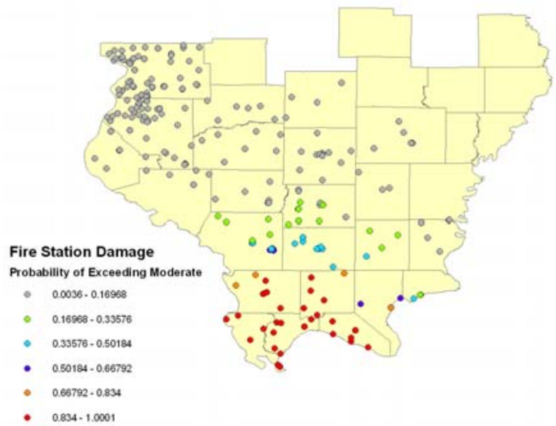


Figure 110: Probability of Exceeding Moderate Damage for Fire Stations

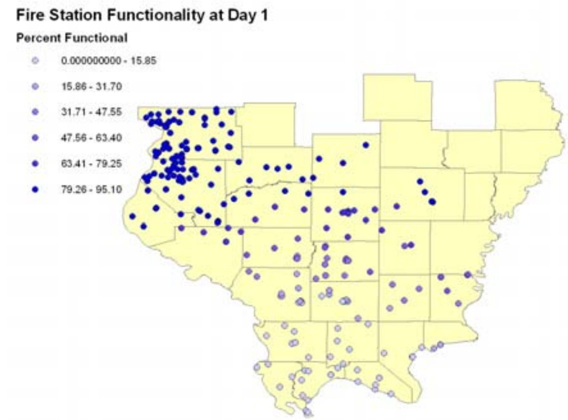


Figure 111: Fire Station Functionality at Day 1

The essential facilities inventory presented in this chapter is an improvement over the HAZUS default essential facilities inventory. The inventory is more detailed than the HAZUS inventory. The essential facilities are for 31 counties in Illinois are based on tax assessor's data. The inventory contains real building type information and contains a larger number of essential facilities than the default HAZUS inventory.

8. Improved Bridge Inventory

A database of state owned bridges was provided to this study by the Illinois Department of Transportation (IDOT) (Ahrens, 2006). The database includes many bridge attributes, such as facility carried, features crossed, main structure type, deck width, number of spans, total length, skew angle, original construction year, reconstruction year, and much more.

8.1 IDOT Bridge Classification

Because the IDOT bridge inventory contained such a large number of bridge attributes, a sensitivity analysis was conducted to determine the bridge characteristics that affect the estimated damage to bridges in HAZUS. Liquefaction was not included in the sensitivity analysis. According to the HAZUS Technical Manual, bridge length and skew angle only affect the damage estimate if liquefaction is included in the HAZUS analysis. In the sensitivity analysis, changing the total bridge length and individual span length did not affect the damage results. However, the bridge class did affect the damage results. It was determined that when liquefaction is ignored, only the bridge class affects the damage estimates to bridges. This conclusion is consistent with the HAZUS Technical Manual.

Therefore, the information used from the IDOT bridge database was bridge location (latitude and longitude) and the bridge classification. IDOT classifies bridge types differently than HAZUS, so the IDOT bridge types were manually matched to the HAZUS bridge types. For cases in which an IDOT bridge type could correspond to more than one HAZUS bridge type, the most vulnerable of the HAZUS bridge type choices was assigned so that the damage results would be conservative.

Many of the bridges in the IDOT inventory fit the criteria for more than one HAZUS bridge type. The definitions of the HAZUS bridge types can be found in Chapter 7 of the HAZUS Technical Manual. A majority of the IDOT bridges could be assigned either to a specific HAZUS bridge type or HAZUS bridge type HWB1, which is a generic bridge type defined as a major bridge of length greater than 150 m. In order to determine which bridge type is more vulnerable in HAZUS, Table 7.7 from the HAZUS Technical Manual was investigated. The latter table gives the damage algorithms for bridges, which are in terms of the spectral acceleration for damage functions due to ground shaking and PGD damage functions due to ground failure. The latter damage functions are used only if liquefaction is included in the analysis. Table 96 gives the spectral acceleration for damage functions due to ground shaking for the bridge types that are applicable to Illinois. Note that only the bridge types that are applicable to the State of Illinois are listed. It was assumed that all existing bridges in the inventory for Illinois were not seismically designed, so all HAZUS bridges types specifying seismic design were ignored. Assuming that no bridges in the Illinois inventory have seismic design may slightly overestimate the damage estimates and was conservative.

Table 96 shows a comparison of the bridge vulnerabilities between the HAZUS bridge types and HAZUS bridge type HWB1. The highlighted cells indicate the bridges that are more vulnerable than HWB1 (i.e., the threshold spectral acceleration values are smaller than those for HWB1, so they will reach any given limit state prior to HWB1). The more vulnerable bridge type was assigned to the bridges that could be defined as either HWB1 or another bridge type.

Table 96: Bridge Types in Illinois and Corresponding Damage Functions

	Sa [1.0 sec in g's] for Damage Functions due to Ground Shaking			
CLASS	**Slight**	**Moderate**	**Extensive**	**Complete**
HWB1	**0.4**	**0.5**	**0.7**	**0.9**
HWB3	0.8	1	1.2	1.7
HWB5	0.25	0.35	0.45	0.7
HWB8	0.35	0.45	0.55	0.8
HWB10	0.6	0.9	1.1	1.5
HWB12	0.25	0.35	0.45	0.7
HWB15	0.75	0.75	0.75	1.1
HWB17	0.25	0.35	0.45	0.7
HWB20	0.35	0.45	0.55	0.8
HWB22	0.6	0.9	1.1	1.5
HWB24	0.25	0.35	0.45	0.7
HWB26	0.75	0.75	0.75	1.1
HWB28	0.8	1	1.2	1.7

= more vulnerable than HWB1

After the HAZUS bridge types were assigned to the IDOT bridge inventory, the IDOT bridge database was imported with some difficulty. The default bridges were deleted from the inventory in HAZUS and then the IDOT bridge database was imported. The default bridges were no longer visible in the inventory menu within HAZUS, but still appeared on the map and in the attributes table for the bridge inventory layer when the imported bridge inventory was mapped in ArcMap. HAZUS only calculated damage for the newly imported bridges, so the remnants of the default bridge database did not affect the damage results. The difficulties in importing the bridges are discussed further in Chapter 13 of this report.

8.2 IDOT Bridge Inventory

Databases of state maintained and locally maintained highway bridges for the entire state of Illinois were provided by the Illinois Department of Transportation (IDOT). The database of state maintained highway bridges contained 7,659 records, and the database of locally maintained bridges contained a total of 18,871 records. The inventory of state-maintained bridges is shown in Figure 112 and the inventory of locally-maintained bridges is shown in Figure 113 below.

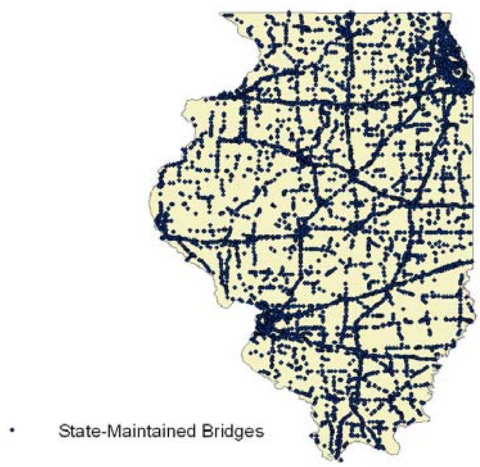


Figure 112: IDOT Inventory for State-Maintained Bridges

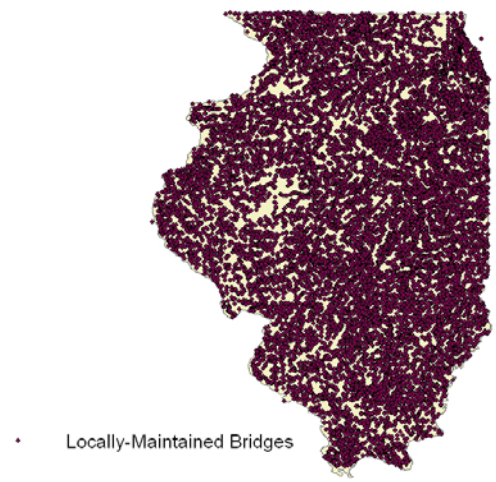


Figure 113: IDOT Inventory for Locally-Maintained Bridges

It was determined that HAZUS is not capable of importing such a large number of records, so the inventory of state maintained bridges for a set of critical counties to study in detail was imported into HAZUS. There were far more locally-maintained bridges, and they could not be imported even into the set of critical counties, so the locally-maintained bridges were imported into Alexander County, Illinois for the purposes of illustration in this report.

8.3 State-Maintained Bridges

The critical counties for which the state-maintained bridges were imported are shown in yellow in 114. The inventory of state maintained bridges is shown in Figure 115 and the inventory of locally maintained bridges in the counties to study in detail is shown in Figure 116. There are approximately 1,930 state-maintained bridges and 4,020 locally-maintained bridges in the set of critical counties. It was determined that there are too many locally-maintained bridges in this southern region to import into HAZUS at once, so locally-maintained bridges were imported into a much smaller region, which is discussed later in this chapter.

Figure 114: Counties in Detailed Study (Counties Shaded in Yellow)

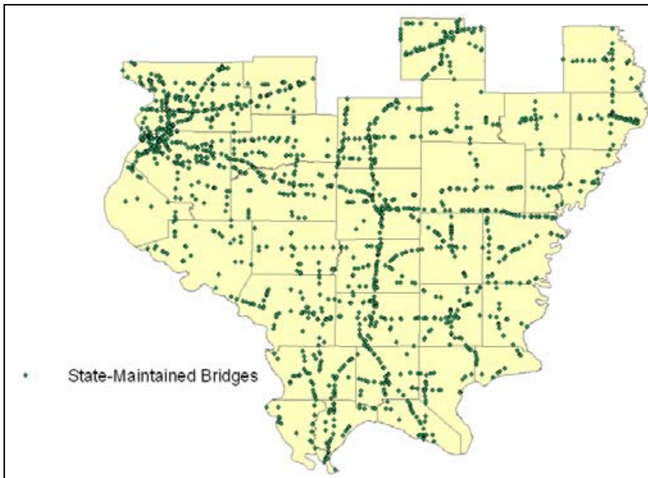


Figure 115: State-Maintained Bridges Inventory in Counties to Study in Detail

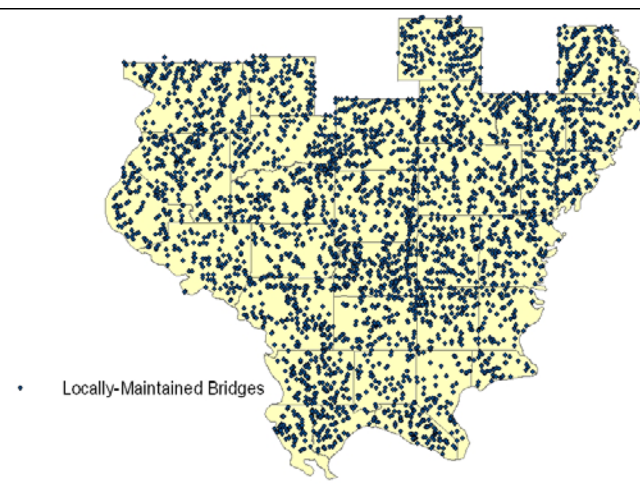


Figure 116: Locally-Maintained Bridges Inventory in Counties to Study in Detail

8.4 Locally-Maintained Bridges

The locally-maintained bridges were imported into only one county in the State of Illinois because there are an extremely large number of locally-maintained bridges in the State, and it was found that HAZUS is not capable of importing large databases. Chapter 13 of this report discusses this importing limitation of the loss estimation tool in more detail. It was determined that HAZUS was able to import the locally-maintained bridges for a study region the size of approximately one county. Therefore, the locally-maintained bridges were imported for only Alexander County in the State of Illinois. There are 68 bridges in the locally-maintained bridge inventory for Alexander County. Figure 117 shows the geographical location of Alexander County within the State.

Figure 117: Location of Alexander County in Illinois

8.5 Damage Estimates

The probability of exceeding moderate damage for the state-maintained bridges in the counties to study in detail is shown in Figure 118.

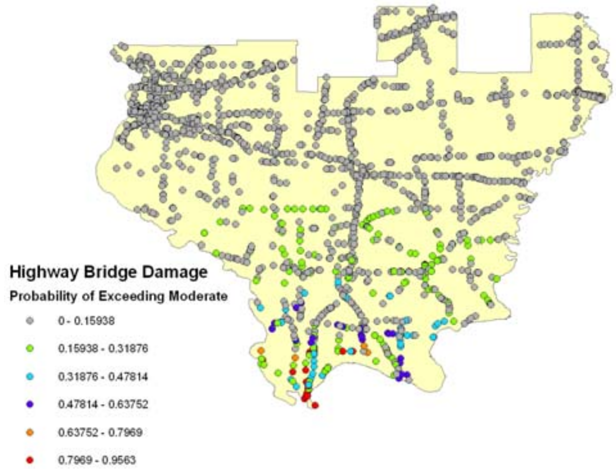


Figure 118: Damage to State-Maintained Bridges in Southern Illinois

The damage to the state-maintained bridges in the counties to study in detail is summarized in Table 97.

Table 97: State-Maintained Highway Bridge Damage in Counties to Study in Detail

	Total	With at Least Moderate Damage	With Complete Damage	With Functionality > 50% After Day 1	With Functionality > 50% After Day 7
Number of Bridges	1927	47	10	1,880	1,903
Percent	%	2.4	0.5	97.6	98.8

HAZUS estimated that 47 state-maintained bridges would suffer at least moderate damage and 10 bridges would be damaged beyond repair if the scenario event were to occur. It does not make sense to compare these damage results with those to the bridges in the default HAZUS inventory because the default HAZUS inventory includes both state-maintained and locally-maintained bridges.

Figure 119 illustrates the locations of locally-maintained bridges in the IDOT inventory in Alexander County, Illinois, and Figure 120 shows the damage, as estimated by HAZUS, to the IDOT bridges in Alexander County.

Figure 119: Location of Locally-Maintained Bridges in Alexander County

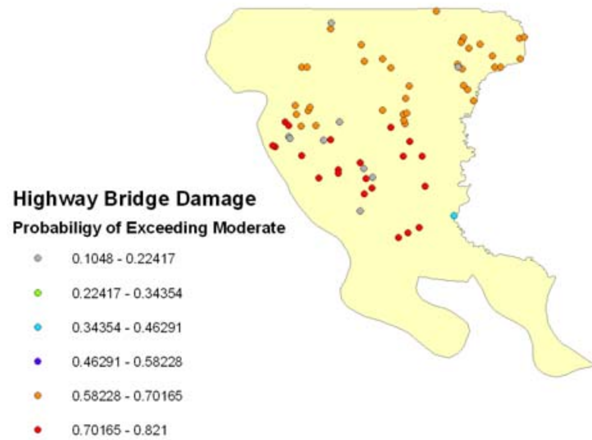


Figure 120: Highway Bridge Damage Probability of Exceeding Moderate Damage (IDOT Bridge Inventory)

The bridge damage estimated by HAZUS is summarized in Table 98.

Table 98: Locally-Maintained Bridge Damage in Alexander County

	Total	With at Least Moderate Damage	With Complete Damage	With Functionality > 50% After Day 1	With Functionality > 50% After Day 7
Number of Bridges	68	58	0	10	10
Percent	%	3.0	0.0	0.5	0.5

HAZUS estimated that 58 of the 68 locally-maintained bridges in Alexander County would suffer at least moderate damage and no bridges would be completely damaged due to the scenario event. It was also estimated that 10 of the highway bridges would have functionality greater than 50 percent on the day of the earthquake, and still only 10 of the bridges would be greater than 50 percent functional one week after the earthquake. The reason that such a large portion of the highway bridge inventory would be significantly damaged is that Alexander County, being at the southern tip of Illinois, is very close to the epicenter of the earthquake. Direct economic losses caused by bridge damage were not estimated because bridge replacement costs were not provided by IDOT.

8.6 Verification of Highway Bridge Damage Estimates

The highway bridge damage estimates from HAZUS were verified using an analysis in which all bridges in the IDOT bridge inventory were assigned the HAZUS bridge type HWB5. When liquefaction is not included, the only bridge characteristic that affects damage probability is the bridge type. Therefore, it was expected that if all bridges were assigned to a single type, the damage probabilities would follow the hazard. Figure 121 shows the ground motion (peak ground acceleration) in the four census tracts in Alexander County, and Figure 122 illustrates the corresponding bridge damage probabilities. The damage probabilities follow the hazard, as expected.

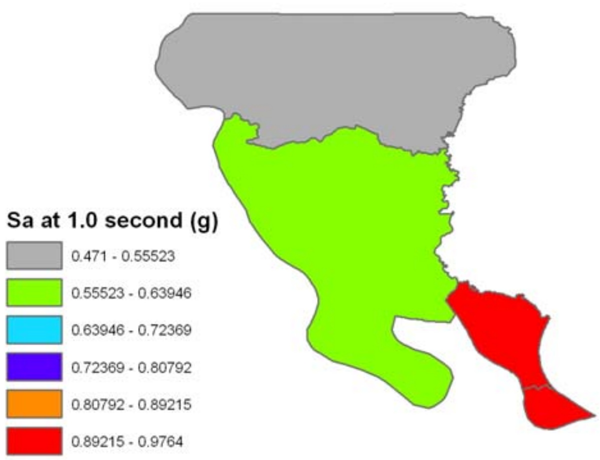


Figure 121: Ground Motion in Alexander County (PGA)

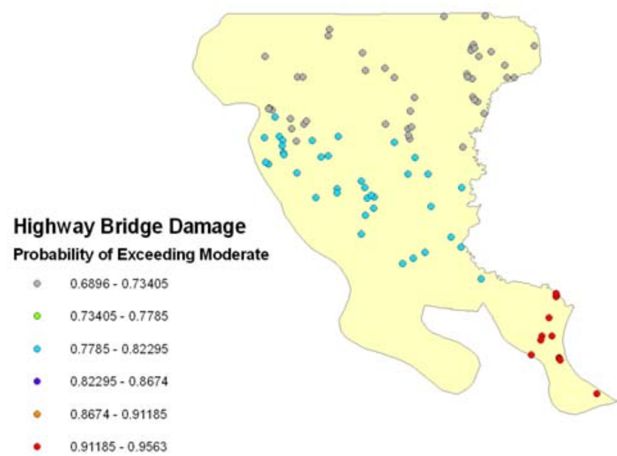


Figure 122: Damage to Highway Bridges (All HWB5 Bridge Type)

8.7 Summary

The bridge inventories presented in this chapter are significant improvements over the default HAZUS bridge inventory, both in number, accuracy, and detail. However, the large number of records, especially for the locally-maintained bridge inventory, prevents successful implementation into HAZUS. The loss estimation tool is capable of only importing only approximately 2,000 bridge records into a region. To estimate losses to the locally-maintained bridges, the inventory must be input into study regions the size of two or three counties, depending on the density of the bridges. Once the loss estimation performed for every subset of the total study regions, the results for the individual study regions must be aggregated. This would prove to be very time consuming, especially for very large regions containing multiple states. It is recommended that the importing capabilities be improved by the developers to facilitate such large projects.

9. Improved Pipelines Inventory

The default utility systems inventory in HAZUS does not contain pipeline inventory based on data about any real pipelines. The default pipeline length estimates are simply based on the road length within the study region. If damage for specific pipelines is desired, the user must supply pipeline data to the loss estimation tool. HAZUS supports importing user-supplied pipelines for the oil, natural gas, potable water, and wastewater utility systems. In this study, oil and natural gas utility pipelines were imported into HAZUS. The pipelines were obtained from FEMA'S HSIP Gold Dataset (Office of Americas/North America & Homeland Security Division, 2005).

9.1 HSIP Gold Dataset Pipeline Inventory

The improved pipeline inventory was obtained from FEMA'S HSIP Gold Dataset. The HAZUS pipeline class (brittle pipes or ductile pipes) could not be determined from the information provided in the HSIP Gold Dataset, so the classes "ODFLT" (oil default) and "GDFLT" (natural gas default) were assigned to all oil pipelines and all natural gas pipelines, respectively. These pipeline classes are consistent with a HAZUS analysis that that was provided by FEMA which included oil and natural gas pipelines from the HSIP Gold Dataset (FEMA, 2006c).

The pipeline database in the HSIP Gold Dataset specifies the commodity carried by each pipeline. The commodities include crude, LPG/NGL, natural gas, petrochemical, refined products, and miscellaneous. The miscellaneous category includes commodities such as acetylene, ammonia, carbon dioxide, fiber optic, helium, hydrogen, methanol, nitrogen, oxygen, product gas, and others. It was assumed that the oil and natural gas system pipelines carried the following commodities.

Oil pipeline (ODFLT) commodities:

- Crude
- Refined products
- Petrochemical

Natural gas pipeline (GDFLT) commodities:

- Natural gas
- LPG/NGL

The HSIP Gold Dataset database contained many pipelines with a diameter specified to be zero. The pipeline diameters for the pipelines with a diameter of zero were calculated using the average non-zero diameter for the given line type. The average diameters for each line type are as listed below. These diameters were used to replace every zero diameter pipeline in the database.

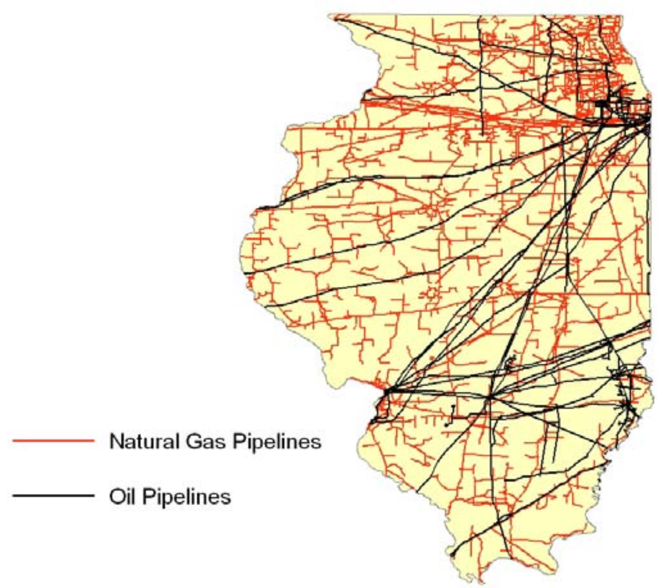


Figure 123: Natural Gas Pipelines and Oil Pipelines HSIP Gold Dataset Inventory

- Transmission/trunk line: 17 inches
- Gathering system main line: 8 inches
- Gathering system field line: 6 inches
- Local distribution: 7 inches

9.2 Pipeline Damage

The pipelines were imported (shown in Figure 123), a HAZUS analysis was run, and the damage to pipelines was estimated. The break rate for pipelines and natural gas pipelines is illustrated in Figure 124 and Figure 125, respectively. The break rates for oil pipelines and natural gas pipelines range from no breaks to about 0.005 breaks/km and from no breaks to about 0.015 breaks/km. These very low break rates are in part due to the fact that liquefaction was not included in this analysis.

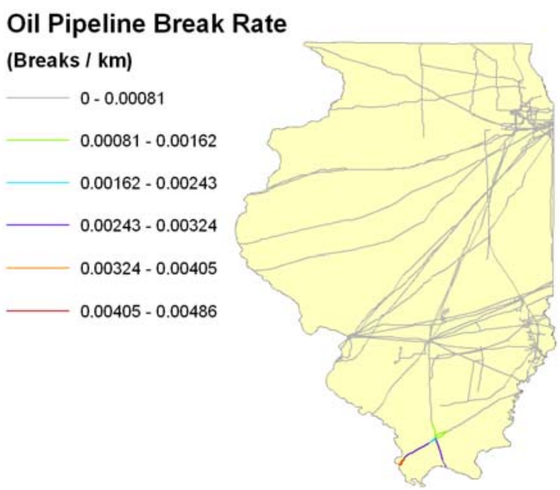


Figure 124: Oil Pipeline Break Rate

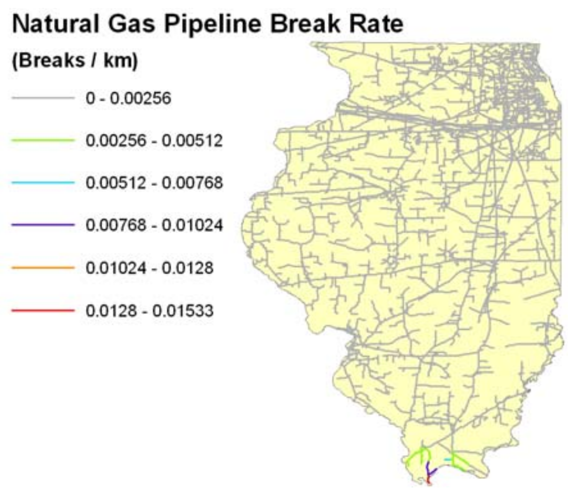


Figure 125: Natural Gas Pipeline Break Rate

It was determined that there is an error in the HAZUS calculations for total pipeline damage. The leak, break, and repair rates for the pipelines were greater than zero, but HAZUS incorrectly estimated that the total leaks, breaks, and repairs were equal to zero. The corrected number of leaks, breaks, and repairs were computed by multiplying each leak, break, and repair rate, which are in units of leaks/km, breaks/km, and repairs/km of pipe, by the corresponding pipeline length outside of HAZUS. The pipeline distances were measured in decimal degrees by default in ArcMap, so it was necessary to re-project the pipelines into a projection that using a metric unit for distance. The total leaks, breaks, and repairs were summed for all pipelines in the region, and these results are shown in Table 99.

Table 99: Pipeline Damage, HSIP Gold Dataset Pipeline Inventory

System	Total Pipeline Length (km)	Number of Leaks	Number of Breaks	Number of Repairs
Natural Gas	25,712	17	4	21
Oil	11,832	8	2	9

Table 100 shows the estimated damage to natural gas and oil pipelines using the HAZUS default pipeline inventory. HAZUS does not estimate any pipeline length or damage to oil pipelines by default. HAZUS estimates a greater pipeline length, and therefore a greater number of leaks and breaks using its default inventory than using the HSIP Gold Dataset inventory. The HSIP Dataset contains major distribution pipelines but does not include smaller, local distribution pipelines. Therefore, using the HSIP Dataset is only beneficial in estimating the damage to these larger pipelines.

Table 100: Pipeline Damage, HAZUS Default Pipeline Inventory

System	Total Pipeline Length (km)	Number of Leaks	Number of Breaks
Natural Gas	106,159	6616	1654
Oil	0	0	0

9.3 Pipeline Functionality

A sensitivity test was performed to determine how pipeline diameter affects damage results. The test was performed by changing the diameters of the pipelines imported into HAZUS and comparing the resulting damage results from the loss estimation tool. The sensitivity test determined that the pipeline diameter has no effect on the pipeline damage estimates. This result agrees with the HAZUS Technical Manual. Table 101 shows the damage algorithms used in HAZUS, where "R.R." is the repair rate or number of repairs for km of pipe. The pipeline damage depends only on the peak ground velocity or the peak ground deformation and the type of pipeline (brittle or ductile).

Table 101: Damage Algorithms for Oil Pipelines in HAZUS

	PGV Algorithm		PGD Algorithm	
	$R.R. \cong 0.0001 \times PGV^{(2.25)}$		$R.R. \cong Prob[liq] \times PGD^{(0.56)}$	
Pipe Type	Multiplier	Example of Pipe	Multiplier	Example of Pipe
Brittle Oil Pipelines (OIP1)	1	Steel Pipe w/ GasWJ	1	Steel Pipe w/ GasWJ
Ductile Oil Pipelines (OIP2)	0.3	Steel Pipe w/ ArcWJ	0.3	Steel Pipe w/ ArcWJ

However, the pipeline diameter affects the restoration functions, which are used to calculate the functionality of pipelines at given intervals after the earthquake. The restoration functions for oil pipelines are shown in Table 102.

Table 102: Restoration Functions for Oil Pipelines

Class	Diameter from: [in]	Diameter to: [in]	# Fixed Breaks per Day per Worker	# Fixed Leaks per Day per Worker	# Available Workers	Priority
a	60	300	0.33	0.66	User-specified	1 (Highest)
b	36	60	0.33	0.66	User-specified	2
c	20	36	0.33	0.66	User-specified	3
d	12	20	0.50	1.0	User-specified	4
e	8	12	0.50	1.0	User-specified	5 (Lowest)
u	Unknown diameter	or for Default Data Analysis	0.50	1.0	User-specified	6 (lowest)

The number of leaks and breaks for small and large pipelines is tabulated in Table 103. A small pipeline is a pipeline with a diameter smaller than 20 inches, and a large pipeline is any pipeline with a diameter of 20 inches or larger. The pipeline size (large or small) affects the time required to repair the pipeline, as shown in Table 102 and the equation above.

Table 103: Breaks and Leaks in Small and Large Pipelines

System	Small Pipeline Leaks	Small Pipeline Breaks	Large Pipeline Leaks	Large Pipeline Breaks
Natural Gas	11	3	6	1
Oil	5	1	3	1

As stated previously, the total leaks, breaks, and repairs, as estimated HAZUS, were equal to zero. Because HAZUS estimated zero leaks, breaks, and repairs, the program always estimated that the pipeline functionality was 100%. To remedy this error, the time required to repair the pipelines was calculated outside of HAZUS using the following equation from Section 8.1.7 from the HAZUS Technical Manual.

Days needed to repair pipelines =

$$\left(\frac{1}{\#available\_workers}\right)\left(\begin{array}{l}\dfrac{\#small\_pipe\_leaks}{1.0}+\dfrac{\#small\_pipe\_breaks}{0.5}\\ +\dfrac{\#large\_pipe\_leaks}{0.66}+\dfrac{\#large\_pipe\_breaks}{0.33}\end{array}\right)$$

The time required to repair the natural gas and oil pipelines was calculated for the cases that 10, 20, 30, or 40 workers are available to repair the pipelines. It is estimated that if 40 workers are available, it would take slightly over one day to repair all pipeline damage that was estimated by HAZUS.

Table 104: Number of Days Required to Repair Pipelines

Number of Available Workers	Days to Repair Pipelines: Natural Gas	Oil	Total
10	3.0	1.4	4.3
20	1.5	0.7	2.2
30	1.0	0.5	1.4
40	0.7	0.3	1.1

9.4 Summary

This section provides a basis for importing pipelines into HAZUS and calculating total damage outside of the loss estimation tool. Oil and natural gas utility pipelines from FEMA'S HSIP Gold Dataset were used to improve the HAZUS utility systems inventory. The HSIP Dataset contains major distribution pipelines but does not include smaller, local distribution pipelines. The use of the default HAZUS inventory provided a more realistic damage and loss estimates for the total pipeline system (i.e., major distribution pipelines and local pipelines). The use of the HSIP Dataset pipelines was beneficial in estimating the damage to the major distribution pipelines.

10. Improved Building Fragilities

The methods for developing structural fragility curves vary in current research. Fragility curves can be developed using empirical results, expert judgment, analytical results, or a combination of these. Each methodology has inherent advantages and disadvantages. The fragility curves used in HAZUS and curves using the Parameterized Fragility Analysis Method (PFM) used to improve the HAZUS damage results are discussed in this chapter. The advantages of the PFM are that the reliability of the parameters is quantifiable, the fragility parameters can be developed for any magnitude of earthquake, there is no opportunity for the results to contain bias, and the probabilistic fragility curves can be developed relatively quickly (Jeong, 2006).

10.1 HAZUS Building Fragility Parameters

The fragility curves in HAZUS were developed using expert judgment and from past earthquakes (FEMA, 2006b). Because the fragility recommendations depend on the individual experience of the experts, it is not possible to quantify the uncertainty in the fragility parameters. Earthquakes of large magnitude occur relatively infrequently, so the empirical data available from past events is very limited to small events. For these reasons, it is believed that the HAZUS default fragility parameters should be replaced by fragility parameters developed using more reliable means.

The form of the fragility curves in HAZUS is shown in the equation below. The fragilities are in terms of spectral displacement.

$$P\left[ds \middle| S_d\right] = \Phi\left[\frac{1}{\beta_{ds}} \ln\left(\frac{S_d}{\bar{S}_{d,ds}}\right)\right]$$

where: $\bar{S}_{d,ds}$ is the median value of spectral displacement at which the building reaches the threshold of damage state, ds,

βds is the standard deviation of the natural logarithm of spectral displacement for damage state, ds, and

Φ is the standard normal cumulative distribution function.

10.2 PFM Building Fragility Parameters

A set of fragility curves for the 36 building types in HAZUS were developed using PFM (Jeong, 2006). The fragility curve parameters are provided in the file "Parameterized Fragilities Using HAZUS Pushover and LSs.xls" on the CD provided in Appendix A of this report.

The capacity for the development of the PFM fragility parameters were provided by default pushover curves in HAZUS for the 36 building types, and the HAZUS limit states were used. The demand was developed by simulation of single degree of freedom inelastic structures, which is an improvement over the expert opinion used in the HAZUS fragilities. Simulation was used to calculate the maximum response of inelastic SDOF structures based on dynamic analysis using real earthquake scenarios for the Memphis, Tennessee Lowlands. Three earthquake scenarios were used: 7.5M event at Blytheville, AR, 6.5M event at Marked Tree, AR, and a 5.5M event at Memphis, TN. The fragility curves were developed for the three intensity measures of PGA, S_a at 0.2 second, and S_a at 1.0 second.

The equation below describes the fragility curves developed. The fragility curve parameters (λ and β) are provided in the file "Parameterized Fragilities Using HAZUS Pushover and LSs.xls" on the CD provided in Appendix A of this report.

$$P(LS/e) = \Phi\left(\frac{\ln(e) - \lambda}{\beta}\right)$$

where:

$P(LS/\mathrm{e})$	=	Probability of exceeding a limit state at a given earthquake intensity
Φ	=	Standard normal cumulative distribution function
e	=	Spectral acceleration
λ, β	=	Modification parameters

The PFM fragility curves are not in a form that can be directly input into HAZUS because they are in terms of spectral acceleration, and the HAZUS fragility curves are in terms of spectral displacement. There is not a simple method of converting the fragility curves in terms of one response parameter to be in terms of the other response parameter. Instead of replacing the fragility curves in HAZUS with the improved fragility curves, an analysis was run using the HAZUS default fragility curves, and the damage estimates were multiplied by modification factors. The development of the damage modification factors is described in the following section.

10.3 Conversion from HAZUS to PFM Damage

First, HAZUS was run using a region consisting of one census tract near Memphis, Tennessee, and the probability of reaching the each limit state (Slight, Moderate, Extensive, and Complete) were tabulated for every building type and for every design level. The results were tabulated as shown in Table 105. A census tract near Memphis was used because the PFM fragility curves used in this study were developed for the Memphis area.

Table 105: Probability of Reaching or Exceeding the Limit States by the HAZUS Analysis

	LS #1	LS #2	LS #3	LS #4
W1-H				
W1-M				
W1-L				
W1-P				
. . . .				
. . . .				
. . . .				

Next, the probability of damage was calculated using the fragility curves from the parameterized fragility analysis curves. The fragility equation used by Jeong, shown below, was used to calculate the probability of damage for every building type and for every design level. The parameter *e* was set equal to the spectral acceleration in the census tract near Memphis described above. The parameters λ and β were provided in a collection of parameterized fragility curves for the 36 HAZUS building types.

$$P(LS/e) = \Phi\left(\frac{\ln(e) - \lambda}{\beta}\right)$$

where:

$P(LS/\mathrm{e})$	= Probability of exceeding a limit state at a given earthquake intensity
Φ	= Standard normal cumulative distribution function
e	= Spectral acceleration, taken as the spectral acceleration in the census tract studied near Memphis
λ, β	= Modification parameters

The equation above was used to calculate the probability of reaching or exceeding each limit state for every building type and for every design level. The probabilities were tabulated as shown in Table 106.

Table 106: Probability of Reaching or Exceeding the Limit States using the MAEC Fragility Equation

	LS #1	LS #2	LS #3	LS #4
W1-H				
W1-M				
W1-L				
W1-P				
. . . .				
. . . .				
. . . .				

Last, the probability values in Tables 105 and 106 were compared. The damage conversion factors were calculated by calculation the ratio of the PFM probability divided by the HAZUS probability for each limit state for each building type and for each design level. The ratios were tabulated as shown in Table 107.

Table 107: Conversion factors for the HAZUS probabilities to be the Parameterized Fragility Analysis results (PFM probability/HAZUS probability)

	LS #1	LS #2	LS #3	LS #4
W1-H				
W1-M				
W1-L				
W1-P				
. . . .				
. . . .				
. . . .				

The development of the conversion factors are provided in the file "GBS HAZUS to PFM Damage Conversion Factors.xls" provided on the CD in Appendix A of this report. The ratios of PFM probability to HAZUS probability were finally multiplied with the HAZUS probabilities of reaching each limit state for each building type and each design level. The product is a converted probability of reaching or exceeding a limit state from the HAZUS fragility to the PFM fragility. The application of the conversion factors is included in the file "GBS HAZUS to PFM Damage Conversion.xls" provided on the CD in Appendix A of this report. The resulting damage is an estimate of what the PFM fragility curves would produce if they were used to perform the loss estimation. The main improvement over the HAZUS fragilities is that the procedure above includes estimating the demand points by inelastic dynamic analysis.

10.4 Converted Damage Estimates

The following tables show the number of buildings expected to reach or exceed each limit state for the 36 HAZUS building types. The top portion of each table shows the number of buildings expected to reach or exceed each limit state from the HAZUS analysis, and the lower portion shows the improved, or PFM damage estimate. Only the buildings that are in the HAZUS default inventory for the State of Illinois are shown in the tables.

Table 108: HAZUS/PFM Damage Comparison for Wood (W1) Buildings

		W1 - Pre Code	W1 - Low Code	W1 - Moderate Code
	Total Building Count	0	2334020	7065
	At Least Slight		24916	5697
Damage from HAZUS	**At Least Moderate**	No	3536	2927
(number of buildings)	**At Least Extensive**	Inventory	176	546
	Complete		3	51
	At Least Slight		26295	6938
Improved Damage	**At Least Moderate**	No	4036	4801
(number of buildings)	**At Least Extensive**	Inventory	220	546
	Complete		5	146

Table 109: HAZUS/PFM Damage Comparison for Wood (W2) Buildings

		W2 - Pre Code	W2 - Low Code	W2 - Moderate Code
	Total Building Count	8871	3197	13
	At Least Slight	242	46	12
Damage from HAZUS	**At Least Moderate**	78	8	5
(number of buildings)	**At Least Extensive**	8	0	0
	Complete	1	0	0
	At Least Slight	218	43	11
Improved Damage	**At Least Moderate**	59	8	5
(number of buildings)	**At Least Extensive**	4	0	0
	Complete	0	0	0

Table 110: HAZUS/PFM Damage Comparison for Steel (S1) Buildings

		S1L - Pre Code	S1L - Low Code	S1L - Moderate Code
	Total Building Count	931	47	0
	At Least Slight	16	0	
Damage from HAZUS	**At Least Moderate**	8	0	No
(number of buildings)	**At Least Extensive**	1	0	Inventory
	Complete	0	0	
	At Least Slight	14	0	
Improved Damage	**At Least Moderate**	6	0	No
(number of buildings)	**At Least Extensive**	1	0	Inventory
	Complete	0	0	

Table 111: HAZUS/PFM Damage Comparison for Steel (S2) Buildings

		S2L - Pre Code	S2L - Low Code	S2L - Moderate Code
	Total Building Count	1667	248	2
	At Least Slight	41	1	2
Damage from HAZUS	**At Least Moderate**	27	0	1
(number of buildings)	**At Least Extensive**	7	0	0
	Complete	1	0	0
	At Least Slight	34	1	2
Improved Damage	**At Least Moderate**	19	0	1
(number of buildings)	**At Least Extensive**	3	0	0
	Complete	0	0	0

Table 112: HAZUS/PFM Damage Comparison for Steel (S3) Buildings

		S3 - Pre Code	S3 - Low Code	S3 - Moderate Code
	Total Building Count	4213	1381	3
	At Least Slight	174	20	3
Damage from HAZUS	**At Least Moderate**	125	12	3
(number of buildings)	**At Least Extensive**	50	3	1
	Complete	8	0	0
	At Least Slight	163	19	3
Improved Damage	**At Least Moderate**	110	12	3
(number of buildings)	**At Least Extensive**	36	3	1
	Complete	3	0	0

Table 113: HAZUS/PFM Damage Comparison for Steel (S4) Buildings

		S4L - Pre Code	S4L - Low Code	S4L - Moderate Code
	Total Building Count	1902	846	1
	At Least Slight	37	5	1
Damage from HAZUS	**At Least Moderate**	25	2	1
(number of buildings)	**At Least Extensive**	8	0	0
	Complete	1	0	0
	At Least Slight	31	4	1
Improved Damage	**At Least Moderate**	19	2	1
(number of buildings)	**At Least Extensive**	4	0	0
	Complete	0	0	0

Table 114: HAZUS/PFM Damage Comparison for Steel (S5) Buildings

		S5L - Pre Code	S5L - Low Code	S5L - Moderate Code
	Total Building Count	2616	888	2
	At Least Slight	50	6	2
Damage from HAZUS	**At Least Moderate**	26	2	2
(number of buildings)	**At Least Extensive**	8	0	1
	Complete	1	0	0
	At Least Slight	45	5	
Improved Damage	**At Least Moderate**	20	2	Not
(number of buildings)	**At Least Extensive**	5	0	Available
	Complete	0	0	

Table 115: HAZUS/PFM Damage Comparison for Concrete (C1) Buildings

		C1L - Pre Code	C1L - Low Code	C1L - Moderate Code
	Total Building Count	338	22	0
	At Least Slight	3	0	
Damage from HAZUS	**At Least Moderate**	2	0	No
(number of buildings)	**At Least Extensive**	1	0	Inventory
	Complete	0	0	
	At Least Slight	3	0	
Improved Damage	**At Least Moderate**	2	0	No
(number of buildings)	**At Least Extensive**	0	0	Inventory
	Complete	0	0	

Table 116: HAZUS/PFM Damage Comparison for Concrete (C2) Buildings

		C2L - Pre Code	C2L - Low Code	C2L - Moderate Code
	Total Building Count	30336	1180	91
	At Least Slight	1644	12	86
Damage from HAZUS	**At Least Moderate**	880	4	64
(number of buildings)	**At Least Extensive**	231	1	21
	Complete	27	0	2
	At Least Slight	1450	11	80
Improved Damage	**At Least Moderate**	682	4	55
(number of buildings)	**At Least Extensive**	136	1	16
	Complete	9	0	2

Table 117: HAZUS/PFM Damage Comparison for Concrete (C3) Buildings

		C3L - Pre Code	C3L - Low Code	C3L - Moderate Code
	Total Building Count	192	0	0
	At Least Slight	1		
Damage from HAZUS	**At Least Moderate**	1	No	No
(number of buildings)	**At Least Extensive**	0	Inventory	Inventory
	Complete	0		
	At Least Slight	1		
Improved Damage	**At Least Moderate**	1	No	No
(number of buildings)	**At Least Extensive**	0	Inventory	Inventory
	Complete	0		

Table 118: HAZUS/PFM Damage Comparison for Precast Concrete (PC1) Buildings

		PC1 - Pre Code	PC1 - Low Code	PC1 - Moderate Code
	Total Building Count	3309	1389	6
	At Least Slight	107	14	6
Damage from HAZUS	**At Least Moderate**	71	7	5
(number of buildings)	**At Least Extensive**	30	2	2
	Complete	4	0	0
	At Least Slight	98	13	6
Improved Damage	**At Least Moderate**	62	7	5
(number of buildings)	**At Least Extensive**	22	2	1
	Complete	2	0	0

Table 119: HAZUS/PFM Damage Comparison for Precast Concrete (PC2) Buildings

		PC2L - Pre Code	PC2L - Low Code	PC2L - Moderate Code
	Total Building Count	264	7	0
	At Least Slight	3	0	
Damage from HAZUS	**At Least Moderate**	2	0	No
(number of buildings)	**At Least Extensive**	1	0	Inventory
	Complete	0	0	
	At Least Slight	2	0	
Improved Damage	**At Least Moderate**	2	0	No
(number of buildings)	**At Least Extensive**	1	0	Inventory
	Complete	0	0	

Table 120: HAZUS/PFM Damage Comparison for Reinforced Masonry (RM1) Buildings

		RM1L - Pre Code	RM1L - Low Code	RM1L - Moderate Code
	Total Building Count	5691	0	2
	At Least Slight	51		2
Damage from HAZUS	**At Least Moderate**	32	No	1
(number of buildings)	**At Least Extensive**	10	Inventory	0
	Complete	0		0
	At Least Slight	46		2
Improved Damage	**At Least Moderate**	27	No	1
(number of buildings)	**At Least Extensive**	7	Inventory	0
	Complete	0		0

Table 121: HAZUS/PFM Damage Comparison for Reinforced Masonry (RM2) Buildings

		RM2L - Pre Code	RM2L - Low Code	RM2L - Moderate Code
	Total Building Count	24	3	2
	At Least Slight	0	0	2
Damage from HAZUS	**At Least Moderate**	0	0	1
(number of buildings)	**At Least Extensive**	0	0	0
	Complete	0	0	0
	At Least Slight	0	0	2
Improved Damage	**At Least Moderate**	0	0	1
(number of buildings)	**At Least Extensive**	0	0	0
	Complete	0	0	0

Table 122: HAZUS/PFM Damage Comparison for Unreinforced Masonry (URM1) Buildings

		URML - Pre Code	URML - Low Code	URML - Moderate Code
	Total Building Count	442609	245434	1563
	At Least Slight	20352	6708	1554
Damage from HAZUS	At Least Moderate	8511	2273	1462
(number of buildings)	At Least Extensive	2697	457	991
	Complete	718	40	452
	At Least Slight	19440	6515	
Improved Damage	At Least Moderate	7681	2273	Not
(number of buildings)	At Least Extensive	2190	457	Available
	Complete	509	40	

Table 123: HAZUS/PFM Damage Comparison for Manufactured Housing (MH) Buildings

		MH - Pre Code	MH - Low Code	MH - Moderate Code
	Total Building Count	95343	48729	2266
	At Least Slight	34468	8917	2256
Damage from HAZUS	At Least Moderate	24186	4240	2112
(number of buildings)	At Least Extensive	7674	551	1188
	Complete	1258	0	229
	At Least Slight	32963	9142	2313
Improved Damage	At Least Moderate	21446	4240	2255
(number of buildings)	At Least Extensive	5206	551	1388
	Complete	580	0	316

10.5 Summary

The damage for wood buildings (W1) increased when the PFM damage conversion factors were applied. The number of manufactured housing units (MH) increased for the at least moderate damage state for pre-code structures. The number of structures estimated to be in every damage state increased for the moderate-code mobile homes. The damage for every other building type and design level decreased when the PFM damage conversion factors were applied.

PFM fragility curves are more rigorous than the type in HAZUS with demand points based on simulation data rather than expert opinion. Therefore, their use is an improvement over the HAZUS damage results. The process of calculating the damage conversion factors and converting the HAZUS damage proved to be very time consuming. It would be advantageous to develop fragility curves in terms of spectral acceleration for the 36 HAZUS building types and input them directly into the loss estimation tool.

11. Improved Highway Bridge Fragilities

The HAZUS default highway bridge fragilities were replaced by fragilities that were developed using a component level approach (Nielson and DesRoches, 2006). The bridge fragilities were developed as a study for the Mid-America Earthquake Center (MAEC), so the fragilities from Nielson and DesRoches (2006) are referred to as the "MAEC fragilities" in this report. The file "MAEC Bridge Fragility Parameters.xls" on the CD in Appendix A of this report contains the MAEC-developed bridge fragility parameters. The improved fragilities and results are discussed in the following sections.

11.1 Highway Bridge Fragility Parameters

The MAEC fragilities were developed using an analytical methodology using a component level approach described in Nielson and DesRoches (2006). The methodology takes into account the fragilities of the individual bridge components, such as columns, bearing, abutments, etc., and statistically combines the fragilities into an overall fragility for the bridge considered. Nielson and DesRoches state that fragility curves developed using just one bridge component can contain errors up to 50% due to simplification and neglect of the other bridge components (Nielson and DesRoches, 2006).

The bridge types with MAEC-defined fragilities include Simply-Supported Concrete (SS_Concrete), Multi-Span Simply-Supported Concrete (MSSS_Concrete), Multi-Span Simply-Supported Concrete Box Girder(MSSS_ConcBox), Multi-Span Continuous Concrete (MSC_Concrete), Simply-Supported Steel (SS_Steel), Multi-Span Simply-Supported Steel (MSSS_Steel), and Multi-Span Continuous Steel (MSC_Steel). The mapping of HAZUS bridge class to MAEC bridge type is shown in Table 124. Dashes in the MAEC bridge type column indicate that there was not an equivalent MAEC bridge type for the listed HAZUS bridge class. The default HAZUS fragilities were used for such bridge classes.

Table 124: HAZUS Bridge Class to MAEC Bridge Type Mapping

HAZUS Bridge Classes in Illinois Inventory		MAEC Bridge Type
HWB1	Major Bridge - Length > 150m, Conventional Design	--
HWB3	Single Span, Conventional Design	SS_Concrete
HWB4	Single Span, Seismic Design	--
HWB5	Concrete, Multi-Column Bent, Simple Support, Conventional Design	MSSS_Concrete
HWB7	Concrete, Multi-Column Bent, Simple Support, Seismic Design	--
HWB10	Continuous Concrete, Conventional Design	MSC_Concrete
HWB11	Continuous Concrete, Seismic Design	--
HWB12	Steel, Multi-Column Bent, Simple Support, Conventional Design	MSSS_Steel
HWB14	Steel, Multi-Column Bent, Simple Support, Seismic Design	--
HWB15	Continuous Steel, Conventional Design	MSC_Steel
HWB16	Continuous Steel, Seismic Design	--
HWB17	PS Concrete Multi-Column Bent, Simple Support, Conventional Design	MSSS_Concrete
HWB219	PS Concrete Multi-Column Bent, Simple Support, Seismic Design	MSSS_Conc Box
HWB22	Continuous PS Concrete, Conventional Design	MSC_Concrete
HWB23	Continuous PS Concrete, Seismic Design	--
HWB24	Same definition as HWB12 except that the bridge length is less than 20 meters	MSSS_Steel
HWB26	Same definition as HWB15 except that the bridge length is less than 20 meters	MSC_Steel
HWB28	All other bridges that are not classified, including wooden bridges	--

The MAEC fragility curve parameters that were used to replace the default HAZUS values are shown in Table 125.

Table 125: New Fragility Curve Parameters (PGA)

	Slight Damage		Moderate Damage		Extensive Damage		Complete Damage	
HAZUS Bridge Class	**Median**	**Beta**	**Median**	**Beta**	**Median**	**Beta**	**Median**	**Beta**
HWB1	*	*	*	*	*	*	*	*
HWB3	0.35	0.9	1.33	0.9	1.83	0.9	2.5	0.9
HWB4	*	*	*	*	*	*	*	*
HWB5	0.2	0.7	0.63	0.7	0.91	0.7	1.28	0.7
HWB7	*	*	*	*	*	*	*	*
HWB10	0.16	0.7	0.53	0.7	0.75	0.7	1.01	0.7
HWB11	*	*	*	*	*	*	*	*
HWB12	0.24	0.5	0.45	0.5	0.58	0.5	0.85	0.5
HWB14	*	*	*	*	*	*	*	*
HWB15	0.19	0.5	0.32	0.5	0.41	0.5	0.51	0.5
HWB16	*	*	*	*	*	*	*	*
HWB17	0.2	0.7	0.63	0.7	0.91	0.7	1.28	0.7
HWB219	0.22	0.8	0.69	0.8	1.31	0.8	3.39	0.8
HWB22	0.16	0.7	0.53	0.7	0.75	0.7	1.01	0.7
HWB23	*	*	*	*	*	*	*	*
HWB24	0.24	0.5	0.45	0.5	0.58	0.5	0.85	0.5
HWB26	0.19	0.5	0.32	0.5	0.41	0.5	0.51	0.5
HWB28	*	*	*	*	*	*	*	*

* Indicates a HAZUS bridge class that does not have a corresponding MAEC bridge class, so default HAZUS fragility parameters were used.

A comparison of the MAEC and HAZUS highway bridge fragility parameters was conducted. The comparison is shown in Table 126. The median PGA from the MAEC fragilities for all bridge classes for the Slight damage state are smaller than the median PGA for the HAZUS fragilities, therefore, the bridges are more vulnerable to the Slight damage state when using the MAEC fragilities. This is not true for the Moderate, Extensive, or Complete damage states. For these latter damage states, the MAEC fragility curves lead to lower damage than the HAZUS fragilities for the bridge classes of HWB3, HWB5, HWB12, HWB17, and HWB26. The opposite is true for HWB10, HWB15, HWB22, and HWB24, that is the MAEC fragilities indicate a more vulnerable bridge than the HAZUS fragilities.

Table 126: Comparison of MAEC and HAZUS Highway Bridge Fragility Parameters

		Slight Damage		Moderate Damage		Extensive Damage		Complete Damage	
	HAZUS Bridge Class	**Median**	**Beta**	**Median**	**Beta**	**Median**	**Beta**	**Median**	**Beta**
MAEC Bridge Fragility Parameters (used to replace HAZUS parameters in this section)	**HWB3**	0.35	0.9	1.33	0.9	1.83	0.9	2.5	0.9
	HWB5	0.2	0.7	0.63	0.7	0.91	0.7	1.28	0.7
	HWB10	0.16	0.7	0.53	0.7	0.75	0.7	1.01	0.7
	HWB12	0.24	0.5	0.45	0.5	0.58	0.5	0.85	0.5
	HWB15	0.19	0.5	0.32	0.5	0.41	0.5	0.51	0.5
	HWB17	0.2	0.7	0.63	0.7	0.91	0.7	1.28	0.7
	HWB219	0.22	0.8	0.69	0.8	1.31	0.8	3.39	0.8
	HWB22	0.16	0.7	0.53	0.7	0.75	0.7	1.01	0.7
	HWB24	0.24	0.5	0.45	0.5	0.58	0.5	0.85	0.5
	HWB26	0.19	0.5	0.32	0.5	0.41	0.5	0.51	0.5
HAZUS Default Bridge Fragility Parameters	**HWB3**	0.8	0.6	1	0.6	1.2	0.6	1.7	0.6
	HWB5	0.25	0.6	0.35	0.6	0.45	0.6	0.7	0.6
	HWB10	0.6	0.6	0.9	0.6	1.1	0.6	1.5	0.6
	HWB12	0.25	0.6	0.35	0.6	0.45	0.6	0.7	0.6
	HWB15	0.75	0.6	0.75	0.6	0.75	0.6	1.1	0.6
	HWB17	0.25	0.6	0.35	0.6	0.45	0.6	0.7	0.6
	HWB19	0.5	0.6	0.8	0.6	1.1	0.6	1.7	0.6
	HWB22	0.6	0.6	0.9	0.6	1.1	0.6	1.5	0.6
	HWB24	0.25	0.6	0.35	0.6	0.45	0.6	0.7	0.6
	HWB26	0.75	0.6	0.75	0.6	0.75	0.6	1.1	0.6
Percent Difference (%)	**HWB3**	-56.3	50.0	33.0	50.0	52.5	50.0	47.1	50.0
	HWB5	-20.0	16.7	80.0	16.7	102.2	16.7	82.9	16.7
	HWB10	-73.3	16.7	-41.1	16.7	-31.8	16.7	-32.7	16.7
	HWB12	-4.0	-16.7	28.6	-16.7	28.9	-16.7	21.4	-16.7
	HWB15	-74.7	-16.7	-57.3	-16.7	-45.3	-16.7	-53.6	-16.7
	HWB17	-20.0	16.7	80.0	16.7	102.2	16.7	82.9	16.7
	HWB219	-56.0	33.3	-13.8	33.3	19.1	33.3	99.4	33.3
	HWB22	-73.3	16.7	-41.1	16.7	-31.8	16.7	-32.7	16.7
	HWB24	-4.0	-16.7	28.6	-16.7	28.9	-16.7	21.4	-16.7
	HWB26	-74.7	-16.7	-57.3	-16.7	-45.3	-16.7	-53.6	-16.7

11.2 Highway Bridge Damage Results

The HAZUS highway bridge fragility parameters were replaced using the MAEC bridge fragility parameters shown in Table 125. The HAZUS default highway bridge inventory was used in the analysis. The probability of exceeding moderate damage for highway bridges in Illinois using the MAEC fragility parameters was mapped and is shown in Figure 126.

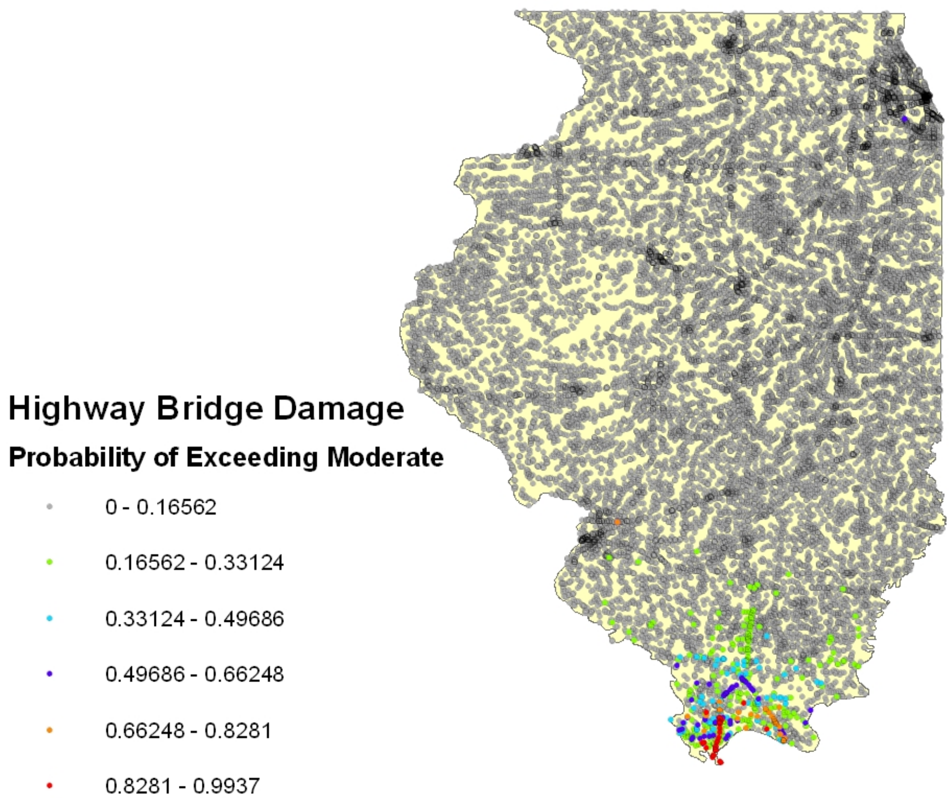


Figure 126: Highway Bridge Damage using MAEC Fragilities

The probability of exceeding moderate damage, when using the default HAZUS fragility parameters is shown in Figure 127. The high probabilities are more concentrated near the earthquake epicenter in the analysis using the improved bridge fragilities, but there are nearly two times as many bridges with high probabilities of experiencing at least moderate damage.

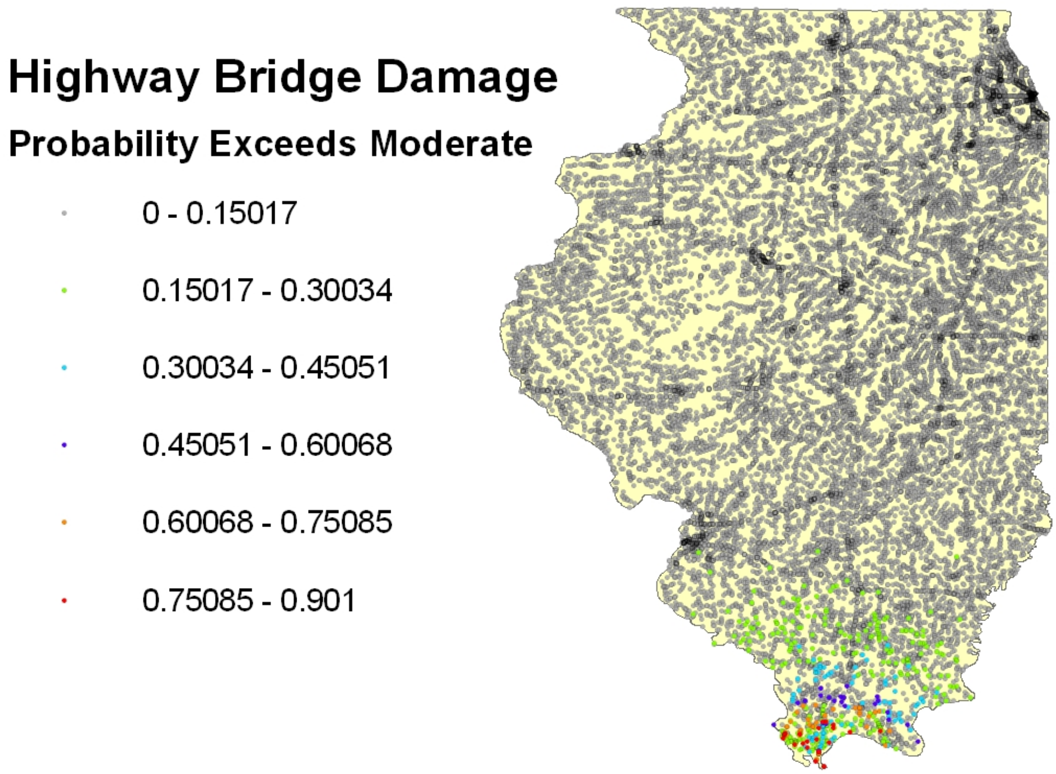


Figure 127: Highway Bridge Damage using Default Fragilities

The highway bridge damage results for both the MAEC and HAZUS fragility parameters are summarized in Table 127. HAZUS estimates that approximately twice as many bridges will be damaged when using the MAEC fragilities as compared to using the HAZUS fragility parameters. It was also estimated that about 33 highway bridges would suffer complete damage when using the MAEC fragility parameters, which is approximately five times more than the number that was estimated when using the HAZUS fragility parameters.

Table 127: Highway Bridge Damage Results

Fragility Parameters	Number of Bridges	With at Least Moderate Damage		With Complete Damage		With Functionality > 50%			
						After Day 1		After Day 7	
		Count	%	Count	%	Count	%	Count	%
MAEC	22,854	121	0.53	33	0.14	22,713	99.38	22,790	99.72
HAZUS		66	0.29	6	0.03	22,794	99.74	22,813	99.82

Because there are many bridges in the State of Illinois that are predicted to remain undamaged due to the scenario event, the number of operational bridges was predicted to be very high. The large number of bridges with no damage overpowers the small number of bridges that have varying damage due to the different fragility models, therefore, the overall state functionality estimates appear to be relatively similar between the bridges using the MAEC fragility parameters and the bridges using the HAZUS fragility parameters.

12. Comparison with CUSEC HAZUS Analysis

A HAZUS analysis for the region including and surrounded by the New Madrid Seismic Zone (NMSZ) was conducted by the Central US Earthquake Consortium – CUSEC. This HAZUS analysis (Blake, 2006) will be referred to as the "CUSEC run" or the "CUSEC analysis" from this point forward. The following sections describe the CUSEC analysis and discuss the results.

12.1 Overview of CUSEC HAZUS Analysis

The CUSEC region included portions of the States of Alabama, Arkansas, Illinois, Indiana, Kentucky, Mississippi, Missouri, and Tennessee. The CUSEC analysis was completed using HAZUS-MH MR1 default inventories, parameters, and calculations. The scenario earthquake was of magnitude 7.7 and located on the southwest segment of the theoretical fault in the New Madrid Seismic Zone. The theoretical fault locations are shown in Figure 128. The ground motions were input in the form of user-defined ground motion maps for Peak Ground Acceleration, Peak Ground Velocity, Sa at 0.3 second, and Sa at 1.0 second.

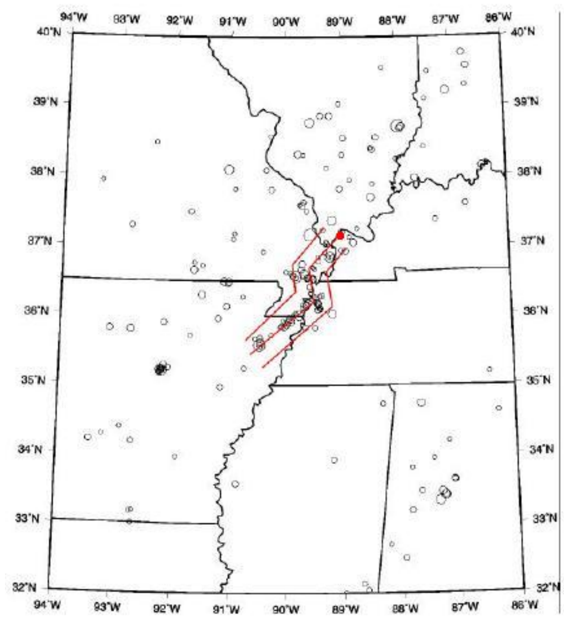


Figure 128: New Madrid Seismic Zone Theoretical Fault Locations

The CUSEC analysis report provided a list of 40 counties that were included in the HAZUS analysis. The study region is shown in Figure 129. The same study region was recreated and run in this study for comparison of results.

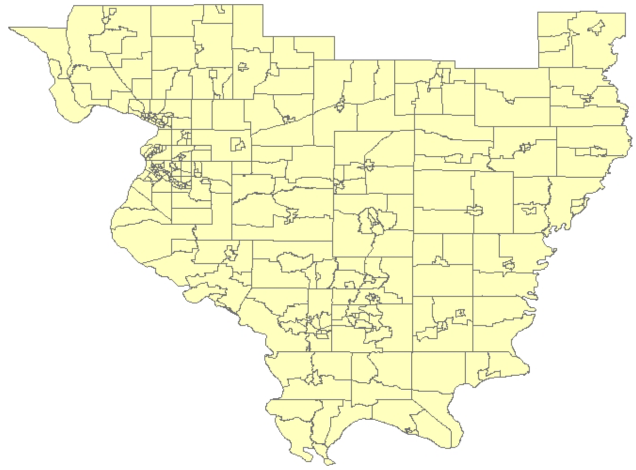


Figure 129: Census Tracts Studied in CUSEC Analysis

The CUSEC results were compared with the results from this study. The main difference in the damage and loss estimates was due to a difference in ground motion. The ground motion differs for the two analyses because the earthquake epicenters are assumed to be in different locations. There may be subtle differences between the results of the two studies because the HAZUS-MH MR1 was used in the CUSEC study, and HAZUS-MH MR2 was used in this study.

12.2 Damage Estimates

The damage estimates for the general building stock, essential facilities, transportation systems, and utility systems are discussed in the following sections.

12.2.1 General Building Stock

Tables 128 and 129 show the expected building damage by occupancy for the CUSEC HAZUS analysis and the HAZUS analysis in this study. Approximately

38.6%, 86.5%, 70.8%, and 52.9% fewer buildings were expected to be completely damaged, extensively damaged, moderately damaged, and slightly damaged, respectively, in the CUSEC study when compared to this study. The number of building estimated to be undamaged increased by 19.3% in the CUSEC study. The increase in damage to the general building stock was due to the fact that the earthquake epicenter in the MAEC study was much closer to Illinois than that in the CUSEC study.

Table 128: Expected Building Damage by Occupancy, CUSEC

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Agriculture	114	0.03	5	0.02	3	0.03	1	0.04	1	0.02
Commercial	2,940	0.73	217	0.87	100	0.98	21	1.41	28	0.65
Education	26	0.01	2	0.01	1	0.01	0	0.01	1	0.02
Government	167	0.04	14	0.06	8	0.07	2	0.11	2	0.06
Industrial	327	0.08	20	0.08	10	0.10	2	0.16	2	0.05
Other Residential	58,602	14.57	8,135	32.78	5,080	49.79	560	36.80	1,082	25.36
Religion	269	0.07	20	0.08	9	0.09	2	0.14	4	0.10
Single Family	339,820	84.48	16,405	66.10	4,992	48.92	933	61.32	3,147	73.75
Total	**402,264**		**24,818**		**10,204**		**1,521**		**4,267**	

Table 129 : Expected Building Damage by Occupancy, MAEC

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Agriculture	89	0.03	17	0.03	12	0.03	4	0.04	2	0.03
Commercial	1,956	0.58	627	1.19	496	1.42	167	1.49	59	0.85
Education	15	0.00	6	0.01	6	0.02	2	0.02	1	0.02
Government	100	0.03	40	0.08	35	0.10	12	0.11	6	0.09
Industrial	218	0.06	64	0.12	58	0.17	18	0.16	4	0.06
Other Residential	27,140	8.05	14,906	28.30	21,266	60.83	7,683	68.33	2,464	35.43
Religion	197	0.06	47	0.09	37	0.11	15	0.13	8	0.12
Single Family	307,533	91.19	36,963	70.18	13,049	37.32	3,343	29.73	4,409	63.40
Total	**337,247**		**52,669**		**34,960**		**11,245**		**6,953**	

12.2.2 Essential Facilities

The expected damage to essential facilities is shown in Tables 130 and 131 for the two studies. This study estimated that many more of each class of essential facility, except emergency, operation centers would suffer at least moderate damage than the

CUSEC study estimated. The number of facilities estimated to be at least moderately damaged decreased by about 94% for medical facilities, 85% for schools, 83% for police stations, and 86% for fire stations. The CUSEC study also estimated that no essential facilities were completely damaged; however, this study does estimate that some essential facilities suffer damage beyond repair. The smaller damage estimates of the CUSEC study are due to the fact that the earthquake epicenter location is relatively distant from the State of Illinois.

Table 130: Expected Damage to Essential Facilities, CUSEC

Classification	Total # of Facilities	With at Least Moderate Damage		With Complete Damage		With Functionality > 50% on day 1	
		Count	%	Count	%	Count	%
Hospitals	53	1	1.9	0	0.0	52	98.1
Schools	727	14	1.9	0	0.0	696	95.7
EOCs	33	5	15.2	0	0.0	27	81.8
Police Stations	202	6	3.0	0	0.0	187	92.6
Fire Stations	242	5	2.1	0	0.0	225	93.0

Table 131: Expected Damage to Essential Facilities, MAEC

Classification	Total # of Facilities	With at Least Moderate Damage		With Complete Damage		With Functionality > 50% on day 1	
		Count	%	Count	%	Count	%
Hospitals	53	16	30.2	1	1.9	32	60.4
Schools	727	91	12.5	9	1.2	571	78.5
EOCs	33	5	15.2	2	6.1	27	81.8
Police Stations	202	36	17.8	6	3.0	141	69.8
Fire Stations	242	37	15.3	7	2.9	173	71.5

12.2.3 Transportation Systems

The damage estimates for the transportation systems are shown in Tables 132 and 133 for the CUSEC study and this study, respectively. This study estimates that 104 more highway bridges will be at least moderately damaged than the number of bridges estimated by the CUSEC study. The CUSEC study and this study estimated that the same number of ferry facilities would be damaged. The CUSEC study estimated that no remaining transportation system components would be at least moderately damaged, but it was estimated that 5 railway bridges, 5 railway facilities, 11 port facilities, and 2 airport facilities would be at least moderately damaged in this study. The increased damage to facilities in this study is due to the fact that the earthquake epicenter is closer to the State of Illinois than in the CUSEC study.

Table 132: Expected Damage to Transportation Systems, CUSEC

System	Component	Locations/ Segments	With at Least Mod. Damage		With Complete Damage		With Functionality > 50 % After Day 1		With Functionality > 50 % After Day 7	
			Count	%	Count	%	Count	%	Count	%
Highway	Segments	1,099	0	0.0	0	0.0	1,088	99.0	1,088	99.0
	Bridges	6,554	5	0.1	0	0.0	6,549	99.9	6,554	100.0
	Tunnels	0	0	--	0	--	0	--	0	--
Railways	Segments	2,023	0	0.0	0	0.0	2,023	100.0	2,023	100.0
	Bridges	197	0	0.0	0	0.0	197	100.0	197	100.0
	Tunnels	0	0	--	0	--	0	--	0	--
	Facilities	60	0	0.0	0	0.0	60	100.0	60	100.0
Light Rail	Segments	1	0	0.0	0	0.0	1	100.0	1	100.0
	Bridges	0	0	--	0	--	0	--	0	--
	Tunnels	0	0	--	0	--	0	--	0	--
	Facilities	0	0	--	0	--	0	--	0	--
Bus	Facilities	16	0	0.0	0	0.0	16	100.0	16	100.0
Ferry	Facilities	2	2	100.0	2	100.0	0	0.0	0	0.0
Port	Facilities	94	0	0.0	0	0.0	94	100.0	94	100.0
Airport	Facilities	122	0	0.0	0	0.0	122	100.0	122	100.0
	Runways	145	0	0.0	0	0.0	145	100.0	145	100.0

Table 133: Expected Damage to Transportation Systems, MAEC

System	Component	Locations/ Segments	With at Least Mod. Damage		With Complete Damage		With Functionality > 50 % After Day 1		With Functionality > 50 % After Day 7	
			Count	%	Count	%	Count	%	Count	%
Highway	Segments	1,099	0	0.0	0	0.0	1,088	99.0	1,088	99.0
	Bridges	6,554	109	1.7	20	0.3	6,453	98.5	6,490	99.0
	Tunnels	0	0	--	0	--	0	--	0	--
Railways	Segments	2,023	0	0.0	0	0.0	2,023	100.0	2,023	100.0
	Bridges	197	5	2.5	0	0.0	192	97.5	192	97.5
	Tunnels	0	0	--	0	--	0	--	0	--
	Facilities	60	5	8.3	0	0.0	57	95.0	59	98.3
Light Rail	Segments	1	0	0.0	0	0.0	1	100.0	1	100.0
	Bridges	0	0	--	0	--	0	--	0	--
	Tunnels	0	0	--	0	--	0	--	0	--
	Facilities	0	0	--	0	--	0	--	0	--
Bus	Facilities	16	0	0.0	0	0.0	16	100.0	16	100.0
Ferry	Facilities	2	2	100.0	2	100.0	0	0.0	0	0.0
Port	Facilities	94	11	11.7	0	0.0	83	88.3	88	93.6
Airport	Facilities	122	3	2.5	0	0.0	120	98.4	121	99.2
	Runways	145	0	0.0	0	0.0	145	100.0	145	100.0

12.2.4 Utility Systems

The expected damage to utility system facilities is summarized in Tables 134 and 135 for both studies. The CUSEC study estimated that no utility system facilities would be more than moderately damaged, however, this study estimated that 5 potable water facilities, 17 waste water facilities, 3 natural gas facilities, 2 electrical power facilities, and 6 communication facilities would suffer at least moderate damage. The difference in damage estimates was due to the difference in ground motion. The ground motions in this study were stronger than those in the CUSEC study. Neither study estimated that any utility system facilities would suffer complete damage.

Table 134: Expected Damage to Utility Systems, CUSEC

System	Total	With at Least Moderate Damage		With Complete Damage		with Functionality > 50 %			
						After Day 1		After Day 7	
	# of Facilities	Count	%	Count	%	Count	%	Count	%
Potable Water	74	0	0.0	0	0.0	74	100.0	74	100.0
Waste Water	300	0	0.0	0	0.0	282	94.0	300	100.0
Natural Gas	16	0	0.0	0	0.0	16	100.0	16	100.0
Oil Systems	15	0	0.0	0	0.0	15	100.0	15	100.0
Electrical Power	28	0	0.0	0	0.0	26	92.9	28	100.0
Communication	122	0	0.0	0	0.0	122	100.0	122	100.0

Table 135: Expected Damage to Utility Systems, MAEC

System	Total	With at Least Moderate Damage		With Complete Damage		with Functionality > 50 %			
						After Day 1		After Day 7	
	# of Facilities	Count	%	Count	%	Count	%	Count	%
Potable	74	5	6.8	0	0.0	68	91.9	74	100.0
Waste Water	300	17	5.7	0	0.0	269	89.7	292	97.3
Natural Gas	16	3	18.8	0	0.0	13	81.3	16	100.0
Oil Systems	15	0	0.0	0	0.0	15	100.0	15	100.0
Electrical	28	2	7.1	0	0.0	26	92.9	28	100.0
Communicati	122	6	4.9	0	0.0	121	99.2	121	99.2

The estimated damage to utility system pipelines for the CUSEC study and this study are shown in Tables 136 and 137, respectively. The number of leaks in the potable water, waste water, and natural gas pipelines are greatly increased by the increased ground motion in this study, as compared to the CUSEC study. The estimated number of leaks increased by a factor of approximately 4.8 for all three types of pipelines, compared to the CUSEC study. The number of breaks increases by a factor of about 2.26. The increased damage is due to the higher ground motion.

Table 136: Expected Utility System Pipeline Damage, CUSEC

System	Total Pipelines Length (kms)	Number of Leaks	Number of Breaks
Potable Water	79,646	610	1491
Waste Water	47,788	483	1179
Natural Gas	31,858	516	1260

Table 137: Expected Utility System Pipeline Damage, MAEC

System	Total Pipelines Length (kms)	Number of Leaks	Number Breaks
Potable Water	79,646	2925	3376
Waste Water	47,788	2313	2670
Natural Gas	31,858	2473	2855

The expected performance of the potable water and electrical power systems for the CUSEC study and this study are presented in Tables 138 and 139, respectively. This study estimated that more 58.3% more households would be without potable water on the day of the earthquake than the CUSEC study. In addition, this study estimated that a higher number of households would be without potable water on 3, 7, and 30 days after the earthquake. The CUSEC study estimated that no households would be without electric power at any time period after the earthquake. There was likely an error in the CUSEC analysis of electric power system performance. It is possible that the module that calculates the performance of the electric power system was not included in the HAZUS loss estimation or that the electric power system inventory was removed for the analysis.

Table 138: Potable Water and Electrical Power System Performance, CUSEC

	Total # of Households	Households without Service									
		At Day 1		At Day 3		At Day 7		At Day 30		At Day 90	
		Count	%	Count	%	Count	%	Count	%	Count	%
Potable Water	524,859	20,357	3.9	17,003	3.2	10,781	2.1	0	0.0	0	0.0
Electric Power		0	0.0	0	0.0	0	0.0	0	0.0	0	0.0

Table 139: Potable Water and Electrical Power System Performance, MAEC

	Total # of Households	Households without Service									
		At Day 1		At Day 3		At Day 7		At Day 30		At Day 90	
		Count	%	Count	%	Count	%	Count	%	Count	%
Potable Water	524,859	32,215	6.1	27,959	5.3	23,766	4.5	5,328	1.0	0	0.0
Electric Power		11,049	2.1	7,235	1.4	3,736	0.7	1,248	0.2	15	0.0

12.2.5 Fire Following Earthquake

The CUSEC study estimated that will be 16 fire ignitions and they will burn about 0.25 square miles of the study region, and this study estimated that there will be 21 fire ignitions that will burn about 0.18 square miles of the study region area. The increase in ignitions is due to the increased ground motion. The number of ignitions and burned area are based on the building square footage and ground motion intensity in the study region. There are also random factors included in the Fire Following Earthquake Module. The difference in burned area between the two HAZUS analyses is due to the fact that random factors are included in the module or the fact that two different versions of HAZUS were used to complete the two studies.

12.2.6 Debris

The CUSEC study estimated that no debris would be generated, but this study estimated that approximately 1 million tons of debris will be generated. The debris estimates are also based on the building square footage and ground motion intensity in the study region. The debris estimates are smaller for the CUSEC analysis because the ground motion is smaller in that analysis.

12.3 Social Losses

Social losses include the number of displaced households, people seeking public shelters, injuries, and casualties. The social loss estimates from HAZUS are discussed in this section.

12.3.1 Displaced Households

The CUSEC study estimated that 5,041 households would be displaced due to the earthquake, and this study estimated that 7,663 households would be displaced. The number of displaced households is based on the portion of buildings in the general building stock that suffer significant damage. The CUSEC study estimated that approximately 1.5 times more buildings will suffer complete damage (due to liquefaction effects) than this study estimated. Therefore, more households were estimated to be displaced is higher in the CUSEC because of the increased number of buildings suffering complete damage.

12.3.2 Injuries and Casualties

The injury and casualty estimates for the three earthquake occurrence times in HAZUS for the CUSEC study and this study are shown in Tables 140 and 141, respectively. This study estimated more casualties and injuries than the CUSEC study for nearly every category of injury, every time of earthquake occurrence, and every general occupancy class. The injury and casualty estimates depend on structural damage to buildings and structural damage to bridges, so the increased building damage and bridge damage, which is due to higher ground motion, in this study causes increased injury and casualty estimates. The number of level 1 injuries was estimated to increase by 2.1, 2.5, and 2.4 at 2 AM, 2 PM, and 5 PM, respectively, in this study due to increased ground motion parameters. The number of level 2 injuries increased by factors of 1.9, 2.2, and 2.2 at the earthquake occurrence times 2 AM, 2 PM, and 5 PM, respectively. The level 3 injuries were estimated to increase by factors of 2.0, 2.2, 2.3 at 2 AM, 2 PM, and 5 PM, respectively. Finally, the number of casualties (level 4 injuries) was estimated to increase by a factor of 2.0 at the earthquake occurrence time of 2 AM and the number of casualties was estimated to increase by a factor of 2.1 at both 2 PM and 5 PM in this study because the ground motion increased due to the nearer earthquake epicenter.

Table 140: Casualty Estimates, CUSEC

		Level 1	Level 2	Level 3	Level 4
2 AM	Commercial	3	1	0	0
	Commuting	0	0	0	0
	Educational	0	0	0	0
	Hotels	6	2	0	0
	Industrial	6	2	0	0
	Other-Residential	280	68	7	12
	Single Family	780	205	23	43
	Total	**1,074**	**277**	**30**	**56**
2 PM	Commercial	265	72	11	21
	Commuting	0	1	1	0
	Educational	103	30	5	9
	Hotels	1	0	0	0
	Industrial	42	12	2	4
	Other-Residential	64	16	2	3
	Single Family	188	50	6	11
	Total	**663**	**182**	**26**	**47**
5 PM	Commercial	251	70	10	20
	Commuting	8	15	21	4
	Educational	9	2	0	1
	Hotels	2	0	0	0
	Industrial	26	7	1	2
	Other-Residential	105	26	3	5
	Single Family	314	84	10	18
	Total	**716**	**205**	**46**	**49**

Table 141: Casualty Estimates, MAEC

		Level 1	Level 2	Level 3	Level 4
2 AM	Commercial	10	2	0	1
	Commuting	0	0	0	0
	Educational	0	0	0	0
	Hotels	14	3	0	1
	Industrial	14	3	0	1
	Other-Residential	831	173	15	28
	Single Family	1,404	356	43	83
	Total	**2,273**	**538**	**60**	**113**
2 PM	Commercial	754	178	23	45
	Commuting	1	2	3	1
	Educational	291	74	11	21
	Hotels	3	1	0	0
	Industrial	101	25	3	6
	Other-Residential	181	39	4	7
	Single Family	339	88	12	21
	Total	**1,671**	**406**	**56**	**101**
5 PM	Commercial	700	169	23	43
	Commuting	22	37	54	11
	Educational	42	9	1	2
	Hotels	4	1	0	0
	Industrial	63	15	2	4
	Other-Residential	309	65	6	11
	Single Family	565	146	19	34
	Total	**1,706**	**443**	**105**	**105**

12.4 Economic Loss Estimates

The loss estimates for the general building stock, essential facilities, transportation systems, and utility systems are discussed in the following sections.

12.4.1 General Building Stock

Tables 142 and 143 show the building-related economic losses for the two studies. This study estimated greater economic losses to buildings for every type of loss and general occupancy class. The increased losses are due to the increased building damage estimated by this study, as compared to the CUSEC study. The total income losses reduced by approximately 71% and the total capital stock losses reduced by approximately 51% in the CUSEC study when compared to the results of this study.

Table 142: Building-Related Economic Losses (Millions of Dollars), CUSEC

Category	Area	Single Family	Other Residential	Commercial	Industrial	Others	Total
Income Loses							
	Wage	0.00	2.08	22.43	0.61	1.88	27.00
	Capital-Related	0.00	0.88	18.69	0.38	0.59	20.54
	Rental	26.09	14.84	9.61	0.18	0.83	51.55
	Relocation	2.66	0.43	0.58	0.02	0.28	3.97
	Subtotal	**28.75**	**18.23**	**51.31**	**1.19**	**3.58**	**103.06**
Capital Stock Loses							
	Structural	146.74	34.61	26.10	4.01	8.09	219.55
	Non_Structural	460.97	132.78	73.56	15.00	24.47	706.78
	Content	121.44	30.10	37.25	9.53	13.04	211.36
	Inventory	0.00	0.00	1.52	2.02	0.27	3.81
	Subtotal	**729.15**	**197.49**	**138.43**	**30.56**	**45.87**	**1,141.50**
	Total	**757.90**	**215.72**	**189.74**	**31.75**	**49.45**	**1,244.56**

Table 143: Building-Related Economic Losses (Millions of Dollars), MAEC

Category	Area	Single Family	Other Residential	Commercial	Industrial	Others	Total
Income Loses							
	Wage	0.00	5.44	100.52	2.84	7.38	116.18
	Capital-Related	0.00	2.38	82.64	1.83	2.19	89.05
	Rental	48.74	39.09	44.14	0.97	3.46	136.40
	Relocation	5.40	1.52	2.84	0.11	1.09	10.96
	Subtotal	**54.13**	**48.43**	**230.15**	**5.76**	**14.12**	**352.59**
Capital Stock Loses							
	Structural	232.15	120.81	107.47	15.63	30.59	506.64
	Non_Structural	724.96	362.45	215.48	34.57	69.27	1,406.73
	Content	202.67	68.48	90.38	20.28	31.88	413.69
	Inventory	0.00	0.00	3.83	4.43	0.78	9.03
	Subtotal	**1,159.78**	**551.74**	**417.15**	**74.91**	**132.51**	**2,336.09**
	Total	**1,213.91**	**600.17**	**647.30**	**80.67**	**146.63**	**2,688.68**

12.4.2 Transportation Systems

The economic losses to the transportation systems are shown in Tables 144 and 145 for the two studies. In all cases, the economic losses to highway systems are estimated to be higher by this study than by the CUSEC study. The losses were greater in this study than in the CUSEC study because of the higher ground motions in this study.

The losses to highway systems, railway systems, bus facilities, port facilities, and airport systems are approximately 78%, 120%, 40%, 66%, and 88% higher in this study than the CUSEC study. The increased transportation system economic losses are due to increased damage to the transportation system components which is due to the nearer earthquake epicenter location to Illinois in this study as compared to the CUSEC study.

Table 144: Transportation System Economic Loss (Millions of Dollars), CUSEC

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Highway	Segments	25,651.10	$119.32	0.47
	Bridges	4,992.46	$79.47	1.59
	Tunnels	0.00	$0.00	0.00
	Subtotal	**30643.56**	**198.79**	
Railways	Segments	3,301.04	$6.94	0.21
	Bridges	22.90	$0.27	1.18
	Tunnels	0.00	$0.00	0.00
	Facilities	145.19	$7.84	5.40
	Subtotal	**3469.13**	**15.05**	
Bus	Facilities	19.36	$1.02	5.27
	Subtotal	**19.36**	**1.02**	
Ferry	Facilities	2.42	$2.42	100.00
	Subtotal	**2.42**	**2.42**	
Port	Facilities	211.07	$17.89	8.48
	Subtotal	**211.07**	**17.89**	
Airport	Facilities	738.04	$32.25	4.37
	Runways	5,002.33	$11.05	0.22
	Subtotal	**5740.37**	**43.30**	
	Total	**40087.67**	**278.47**	

Table 145: Transportation System Economic Loss (Millions of Dollars), MAEC

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Highway	Segments	25,651.10	$193.04	0.75
	Bridges	4,992.46	$160.28	3.21
	Tunnels	0.00	$0.00	0.00
	Subtotal	**30643.56**	**353.32**	
Railways	Segments	3,301.04	$20.76	0.63
	Bridges	22.90	$0.42	1.83
	Tunnels	0.00	$0.00	0.00
	Facilities	145.19	$11.84	8.15
	Subtotal	**3469.13**	**33.02**	
Bus	Facilities	19.36	$1.37	7.09
	Subtotal	**19.36**	**1.37**	
Ferry	Facilities	2.42	$2.42	100.00
	Subtotal	**2.42**	**2.42**	
Port	Facilities	211.07	$29.82	14.13
	Subtotal	**211.07**	**29.82**	
Airport	Facilities	738.04	$52.37	7.10
	Runways	5,002.33	$29.16	0.58
	Subtotal	**5740.37**	**81.53**	
	Total	**40087.67**	**501.48**	

12.4.3 Utility Systems

The losses to the utility systems are shown in Tables 146 and 147 for the CUSEC study and this study, respectively. The losses estimated by the CUSEC study are lower than the losses estimated by this study because the ground motion parameters are lower. The economic loss to the utility system decreased in the CUSEC study by about 51% for the potable water system, 48% for the waste water system, 59% for the natural gas system, 46% for the electric power system, and 44% for the communication system when compared to the utility system economic loss in this study.

Table 146: Utility System Economic Loss (Millions of Dollars), CUSEC

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Potable Water	Pipelines	0.00	$0.00	0
	Facilities	2,735.26	$49.20	1.80
	Distribution	1,592.92	$16.13	1.01
	Subtotal	**4,328.18**	**$65.33**	
Waste Water	Pipelines	0.00	$0.00	0.00
	Facilities	22,177.80	$513.66	2.32
	Distribution	955.75	$12.75	1.33
	Subtotal	**23,133.55**	**$526.41**	
Natural Gas	Pipelines	0.00	$0.00	0.00
	Facilities	19.36	$0.50	2.58
	Distribution	637.17	$13.63	2.14
	Subtotal	**656.53**	**$14.13**	
Oil Systems	Pipelines	0.00	$0.00	0.00
	Facilities	1.67	$0.01	0.66
	Subtotal	**1.67**	**$0.01**	
Electrical Power	Facilities	3,418.80	$72.23	2.11
	Subtotal	**3,418.80**	**$72.23**	
Communication	Facilities	13.54	$0.33	2.44
	Subtotal	**13.54**	**$0.33**	
	Total	**31,552.27**	**$678.44**	

Table 147: Utility System Economic Loss (Millions of Dollars), MAEC

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Potable Water	Pipelines	0.00	$0.00	0.00
	Facilities	2,735.26	$94.93	3.47
	Distribution Lines	1,592.92	$39.61	2.49
	Subtotal	**4,328.18**	**$134.55**	
Waste Water	Pipelines	0.00	$0.00	0.00
	Facilities	22,177.80	$977.37	4.41
	Distribution Lines	955.75	$31.33	3.28
	Subtotal	**23,133.55**	**$1,008.70**	
Natural Gas	Pipelines	0.00	$0.00	0.00
	Facilities	19.36	$1.09	5.62
	Distribution Lines	637.17	$33.49	5.26
	Subtotal	**656.53**	**$34.58**	
Oil Systems	Pipelines	0.00	$0.00	0.00
	Facilities	1.67	$0.01	0.66
	Subtotal	**1.67**	**$0.01**	
Electrical Power	Facilities	3,418.80	$133.94	3.92
	Subtotal	**3,418.80**	**$133.94**	
Communication	Facilities	13.54	$0.59	4.37
	Subtotal	**13.54**	**$0.59**	
	Total	**31,552.27**	**$1,312.38**	

12.5 Summary of Losses

The HAZUS loss estimation study performed by CUSEC had an earthquake epicenter that was much farther from the region of interest (Illinois) than in the earthquake epicenter location used for all studies in this report.

The number of general buildings estimated to be damaged significantly increased in this study due to the higher ground motion parameters. As a result of the increase in completely damaged buildings, this study estimated that about 52% more households would be displaced. The total economic loss to the buildings in the study region was estimated to be approximately 2.16 times higher in this study than in the CUSEC study because of the increased ground motions. The damage to essential facilities was drastically smaller in the CUSEC study because the magnitude of the ground motion parameters was smaller in the CUSEC study. This study estimated increased damage to the transportation system components. The total economic loss to the transportation system was estimated to be increase by 80% in this study.

The estimated damage to utility system components increased due to the increased ground motion in this study, as well. The number of utility system pipeline leaks increased by a factor of approximately 4.8 in this study due to the higher seismic hazard. The total economic losses to the utility system were estimated to increase by 94% in this study because of the increased damage and ground motion.

13. Assessment of HAZUS Loss Assessment Capabilities

During the course of this study, problems and shortcomings in the HAZUS loss estimation tool were discovered. This chapter describes such issues with the HAZUS program.

13.1 Importing Bridge Data

Several issues were encountered in HAZUS when importing the bridge inventory that was provided by IDOT. These issues are described in the following sections.

13.1.1 Remnants of HAZUS Default Bridge Inventory

First, the default bridge records were deleted and replaced with the IDOT bridges within HAZUS, as shown in Figure 130.

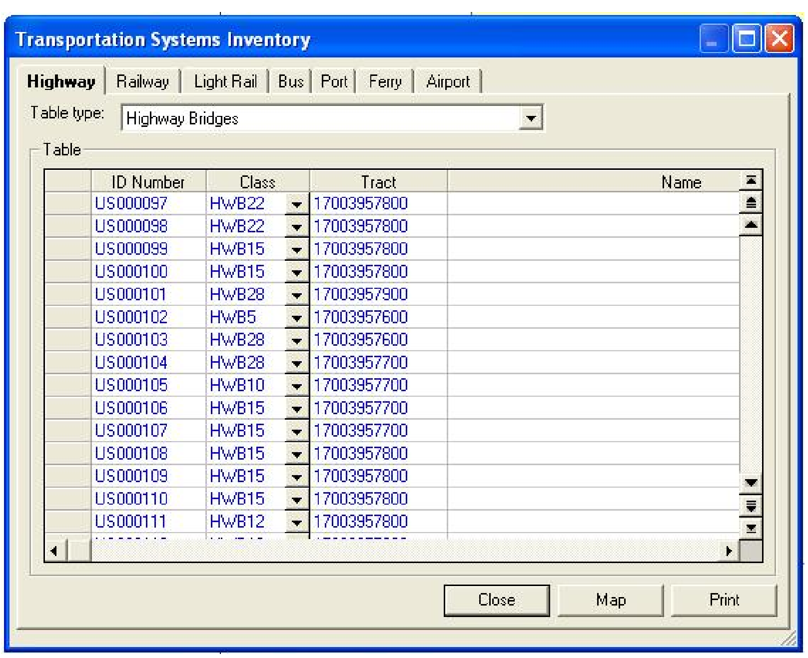


Figure 130: IDOT Bridge Inventory in HAZUS with No Default Records Present

Although no records for the HAZUS default bridge inventory remain in the Transportations Systems Inventory window pictured in Figure 130, remnants of the default bridges remained. Both the IDOT bridges and the HAZUS default bridges displayed on the map of the study region when the bridge inventory was mapped within HAZUS. A close-up of the study region with the mapped bridge locations is shown in Figure 131. The circled bridges are those that have records both in the IDOT inventory and the HAZUS inventory. Two bridge symbols are displayed for the bridges that are in both inventories.

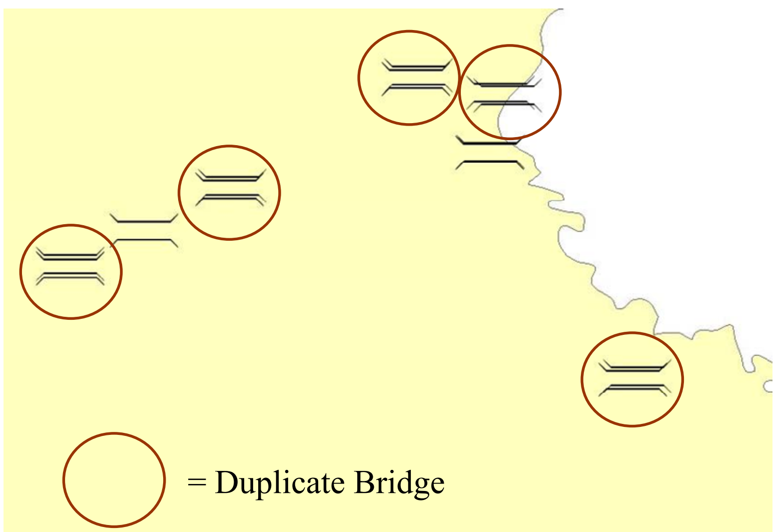
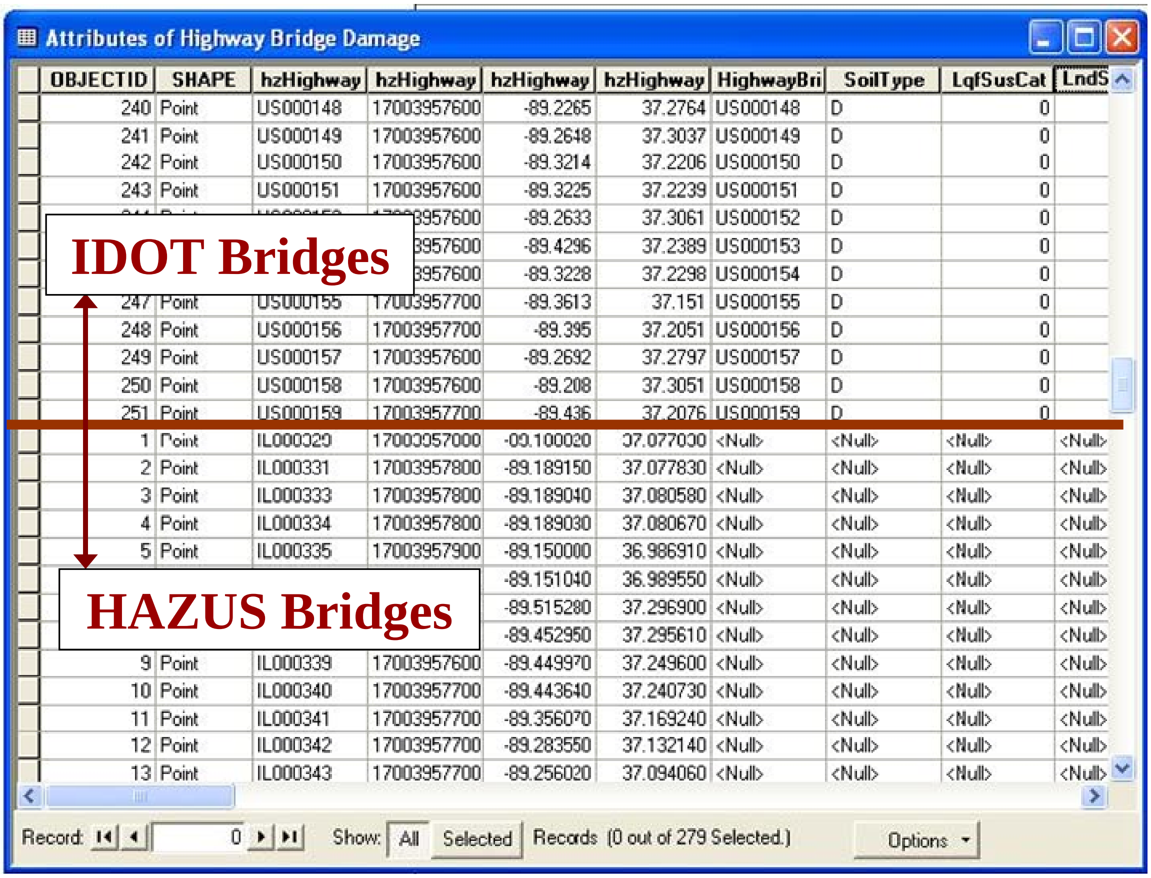


Figure 131: Highway Bridges in Both the HAZUS Inventory and the IDOT Inventory

After the HAZUS analysis was run, and damage was calculated for highway bridges, the damage was mapped. The attributes table of the mapped bridge damage contained records for both the HAZUS bridge inventory and the IDOT bridge inventory; even though the HAZUS bridge inventory was deleted before the IDOT bridge inventory was imported. The attributes table for bridge damage is shown in Figure 132. Two characteristics distinguish the two sets of inventories. First, the IDOT bridge identifiers begin with the letters "US", and the HAZUS bridge identifiers begin with the letters "IL". Second, the fields for all hazard and damage parameters for the HAZUS inventory are filled with the value “<Null>”. Damage probabilities are not calculated for the deleted HAZUS bridge inventory. Both of these characteristics can be seen in the attributes table in Figure 132.



OBJECTID	SHAPE	hzHighway	hzHighway	hzHighway	hzHighway	HighwayBri	SoilType	LqfSusCat	LndS
240	Point	US000148	17003957600	-89.2265	37.2764	US000148	D	0	
241	Point	US000149	17003957600	-89.2648	37.3037	US000149	D	0	
242	Point	US000150	17003957600	-89.3214	37.2206	US000150	D	0	
243	Point	US000151	17003957600	-89.3225	37.2239	US000151	D	0	
[illegible]	[illegible]	[illegible]	[illegible]957600	-89.2633	37.3061	US000152	D	0	
[illegible]	[illegible]	[illegible]	[illegible]3957600	-89.4296	37.2389	US000153	D	0	
[illegible]	[illegible]	[illegible]	[illegible]3957600	-89.3228	37.2298	US000154	D	0	
247	Point	US000155	17003957700	-89.3613	37.151	US000155	D	0	
248	Point	US000156	17003957700	-89.395	37.2051	US000156	D	0	
249	Point	US000157	17003957600	-89.2692	37.2797	US000157	D	0	
250	Point	US000158	17003957600	-89.208	37.3051	US000158	D	0	
251	Point	US000159	17003957700	-89.436	37.2076	US000159	D	0	
1	Point	IL000329	17003957800	-89.188820	37.077030	<Null>	<Null>	<Null>	<Null>
2	Point	IL000331	17003957800	-89.189150	37.077830	<Null>	<Null>	<Null>	<Null>
3	Point	IL000333	17003957800	-89.189040	37.080580	<Null>	<Null>	<Null>	<Null>
4	Point	IL000334	17003957800	-89.189030	37.080670	<Null>	<Null>	<Null>	<Null>
5	Point	IL000335	17003957900	-89.150000	36.986910	<Null>	<Null>	<Null>	<Null>
[illegible]	[illegible]	[illegible]	[illegible]	-89.151040	36.989550	<Null>	<Null>	<Null>	<Null>
[illegible]	[illegible]	[illegible]	[illegible]	-89.515280	37.296900	<Null>	<Null>	<Null>	<Null>
[illegible]	[illegible]	[illegible]	[illegible]	-89.452950	37.295610	<Null>	<Null>	<Null>	<Null>
9	Point	IL000339	17003957600	-89.449970	37.249600	<Null>	<Null>	<Null>	<Null>
10	Point	IL000340	17003957700	-89.443640	37.240730	<Null>	<Null>	<Null>	<Null>
11	Point	IL000341	17003957700	-89.356070	37.169240	<Null>	<Null>	<Null>	<Null>
12	Point	IL000342	17003957700	-89.283550	37.132140	<Null>	<Null>	<Null>	<Null>
13	Point	IL000343	17003957700	-89.256020	37.094060	<Null>	<Null>	<Null>	<Null>

Figure 132: Attributes Table with Imported IDOT and Default HAZUS Bridge Records

Other errors in replacing the bridge inventory in HAZUS were noted during this study. For example, a set of test bridges were added to the inventory manually after deleting the HAZUS bridge inventory. The process of deleting the old records and inserting the new records needed to be repeated multiple times before the new highway bridges correctly displayed in the Transpiration Systems Inventory window and the bridge locations mapped correctly on the study region.

13.1.2 Database Selection Prompt Bypassed

Another error that occurred when importing a bridge inventory was that HAZUS skipped the prompt to select the file in which the bridge inventory is contained. When "Import" was selected, as shown in Figure 133, the option to select a source file was not given.

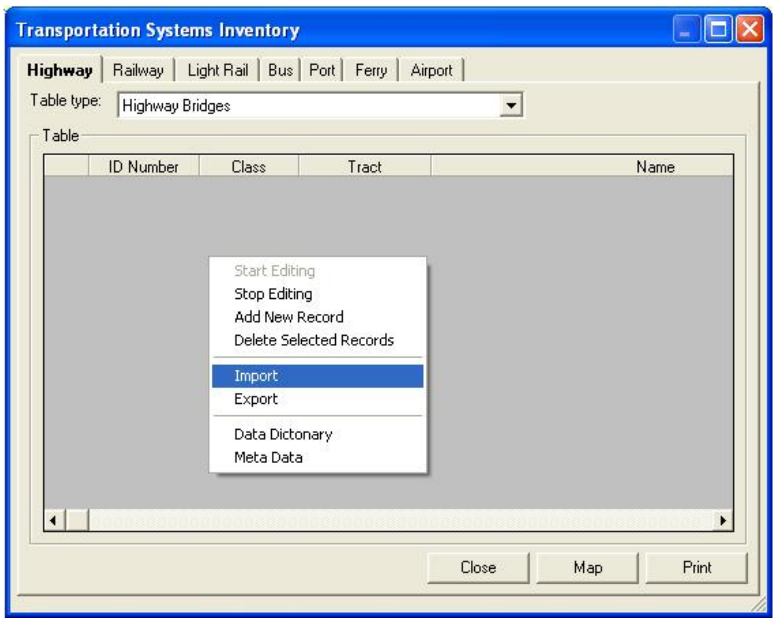


Figure 133: Import a New Inventory Database

The window shown in Figure 134 allows the user to select a file to import and should appear when importing a database, but it often this step was skipped by HAZUS, and the filed mapping window, shown in Figure 135, immediately appeared.

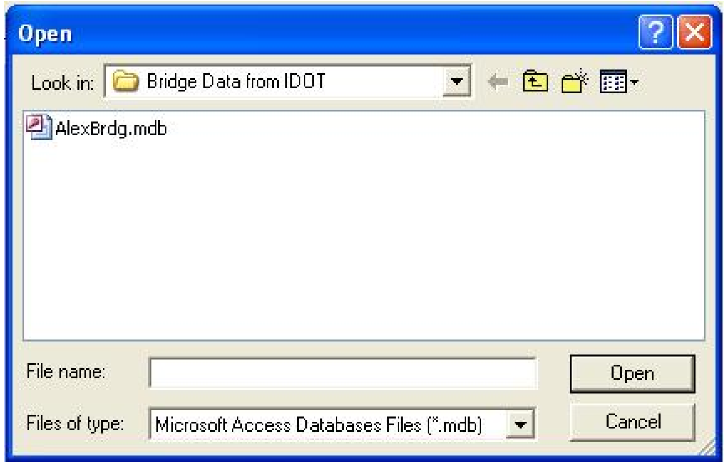


Figure 134: Dialog to Select Source File (Often bypassed by HAZUS)

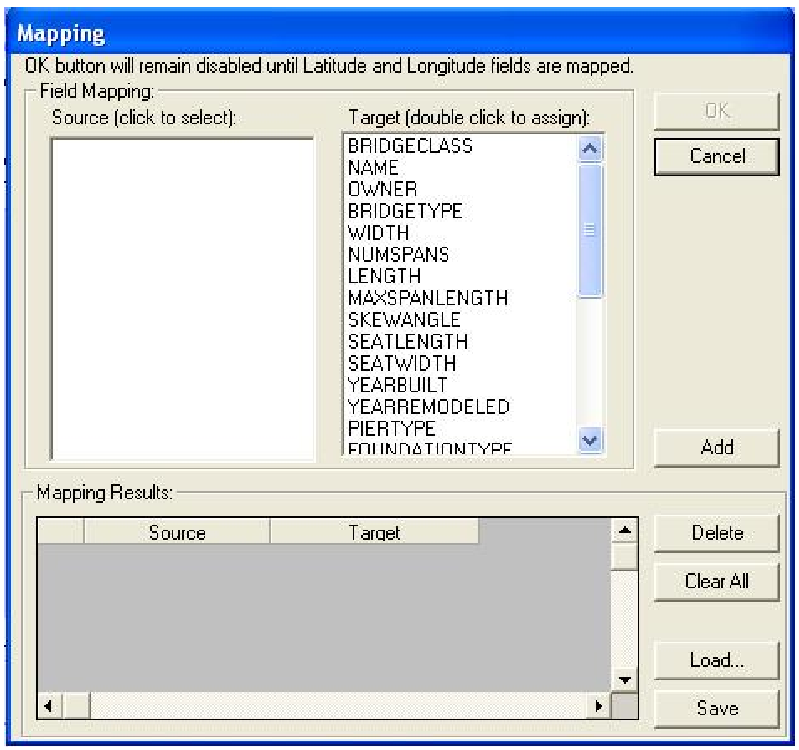


Figure 135: Dialog to Map Source to Target Database Fields

The source and target fields could not be mapped unless HAZUS gave the option to choose a source file. If the file selection dialog was skipped, the source field list appeared empty. This error in HAZUS was overcome by closing the mapping dialog box, and choosing “Import” again. In most cases, this needed to be repeated several times before HAZUS prompted for a source file. There were other cases in which repeating these steps many times did not result in a prompt to select the input file, so a new study region was created, and the importing process was attempted again. These importing errors occurred when importing pipelines as well.

13.1.3 Bridge Inventory Size Limitations

Lastly, it was determined that HAZUS is not capable of importing more than approximately 2,000 bridge records into one study region. The large number of IDOT bridge records (explained in Chapter 8 of this report), especially for the locally-maintained bridge inventory, prevents successful implementation into HAZUS. To estimate losses to the locally-maintained bridges, the inventory must be input into study regions the size of two or three counties, depending on the density of the bridges. Once the loss estimation performed for every subset of the total study regions, the results for the individual study regions must be aggregated. This would prove to be very time consuming, especially for very large regions containing multiple states. It is recommended that the importing capabilities be improved by the HAZUS developers to facilitate such large projects.

13.2 Importing Pipelines

Errors in importing pipelines have been noted as well. The pipeline inventory did not always appear in the Utility Systems Inventory window in HAZUS until they were imported into HAZUS, the program was restarted, and the pipelines were imported again. In some instances, this importing-restarting process needed to be repeated many times before the pipeline inventory correctly displayed in the inventory window and mapped on the study region.

As discussed in the Pipelines section of this report, the leak, break, and repair rates, as estimated by HAZUS, were greater than zero, but the total leaks, breaks, and repairs were equal to zero. As a result, the pipeline damage was calculated outside of HAZUS. These damage calculations are discussed in the Pipelines section of this report.

When importing pipelines, HAZUS did not always prompt the user to select the file containing the new pipeline inventory. This issue is analogous to that when bridges are imported and is discussed thoroughly in the Importing Bridges section of this chapter.

13.3 Ground Motion and Liquefaction

Several problems with the calculations by the Potential Earth Science Hazards (PESH) module in HAZUS were identified during this study. These problems are described in the following sections.

13.3.1 Attenuation Cutoff

HAZUS automatically cut off the ground motion parameters (PGA, PGV, S_a at 0.3 second, and S_a at 1.0 second) to zero in all census tracts that are farther than 200 km from the earthquake epicenter in any deterministic event. This cutoff does not follow the true behavior of the attenuation relationships. In addition, all census tracts with the zeroed ground motion parameters showed incorrect random damage to essential facilities. This issue is discussed and illustrated in the Hazard Definition Chapter of this report.

To remedy the ground motion cutoff errors in HAZUS, user-defined ground motions were used in all sections of this study. The attenuation cutoff and user-defined ground motions are discussed further in the Hazard Definition chapter of this report.

13.3.2 Campbell Attenuation Relationship in HAZUS

In addition to the attenuation cutoff described in the previous section, it the Campbell attenuation relationship embedded in HAZUS is believed to contain errors. The following figures show a comparison between the ground motions produced using the Campbell relationship embedded in HAZUS and the Campbell relationship in the ground motion program that was developed. The plots show that the ground motion predicted by HAUS does not produce a smooth curve, in the way the same attenuation relationship outside of HAZUS does. This is especially apparent in the PGV and S_a comparisons.

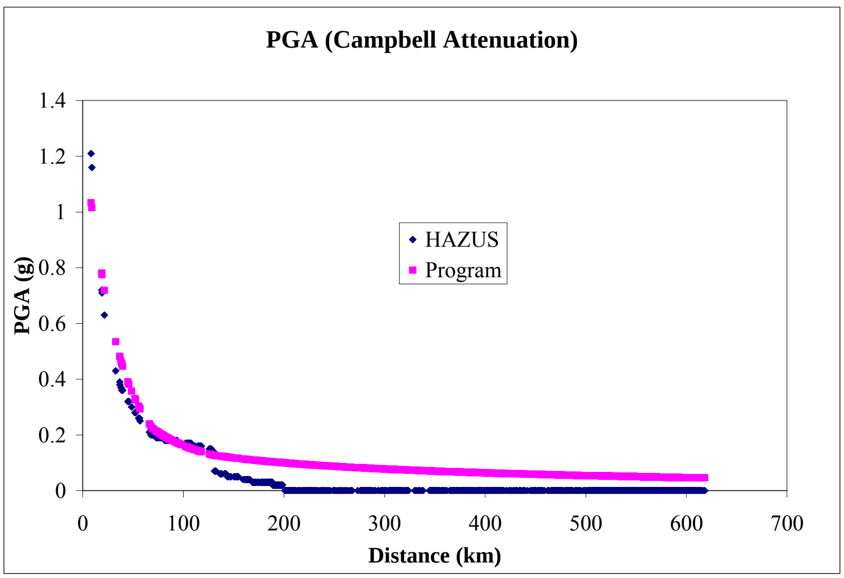


Figure 136: Comparison of Campbell Attenuation (PGA) from HAZUS vs. Ground Motion Program

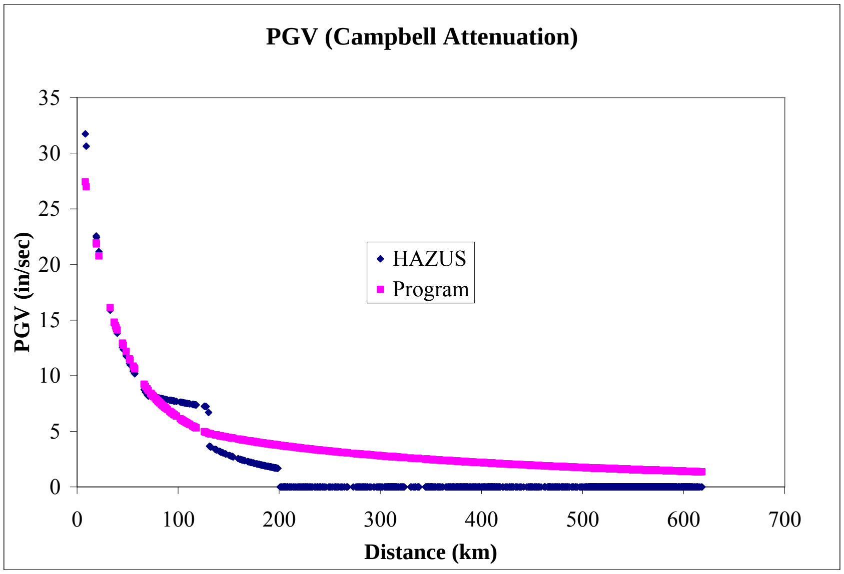


Figure 137: Comparison of Campbell Attenuation (PGV) from HAZUS vs. Ground Motion Program

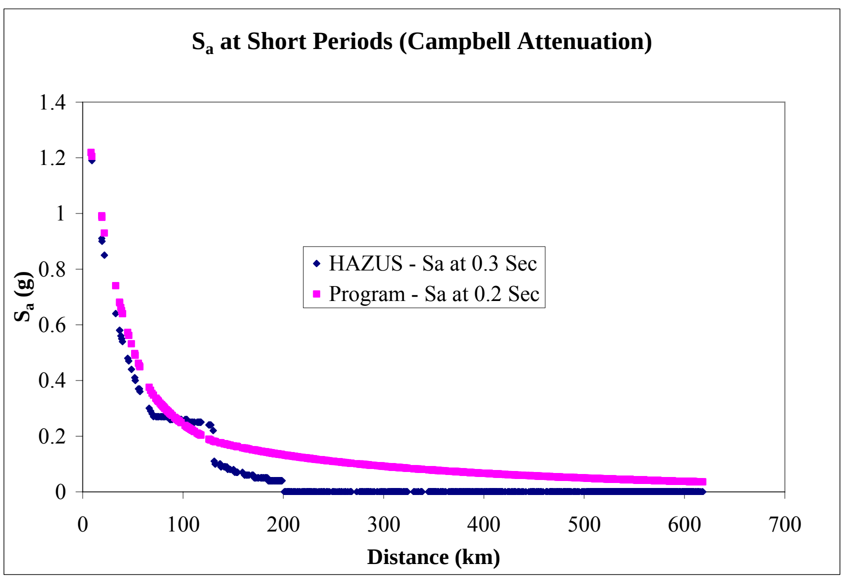


Figure 138: Comparison of Campbell Attenuation (S_a at Short Periods) from HAZUS vs. Ground Motion Program

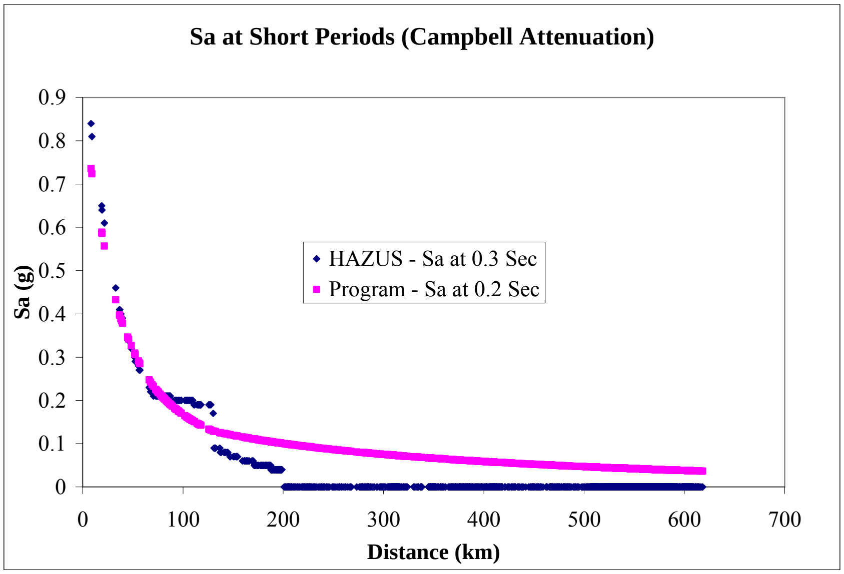


Figure 139: Comparison of Campbell Attenuation (S_a at 1.0 Second Period) from HAZUS vs. Ground Motion Program

13.3.3 Liquefaction Calculations for Very Low Susceptibility

Liquefaction is computed correctly for all but the “very low” liquefaction susceptibility category. The expected permanent ground displacement (PGD) was computed outside of HAZUS for a set of census tracts. The calculations were done six times. First it was assumed that all tracts had soil with a liquefaction susceptibility of “none”. Then “very low” was assumed, followed by “low”, “moderate”, “high”, and “very high”. The estimated PGD was calculated six times using HAZUS by assuming that every census tract in the region be uniform liquefaction susceptibility.

The calculations within HAZUS and outside of HAZUS were compared, and it was determined that the permanent ground displacement due to liquefaction is calculated correctly by HAZUS for all liquefaction susceptibility indices except “very low”. For this index, HAZUS incorrectly estimates a permanent ground displacement of zero for any PGA value. To remedy this issue, all census tracts with a liquefaction susceptibility index of “very low” were assigned an index of “low”. The liquefaction calculations are also discussed in the Hazard Definition chapter of this report.

13.3.4 Ground Motion when Liquefaction is Included

In several HAZUS analyses, the Potential Earth Science Hazards (PESH) module incorrectly modified not only the ground deformation but also the ground motion parameters. The input ground motion was calculated using the user-supplied ground motion maps that were developed using the ground motion program as described in the Hazard Definition chapter of this report. The ground motion maps and the liquefaction susceptibility map were imported into HAZUS and the analysis was run.

The PESH module reduced the ground motion parameters (PGA, PGV, S_a at 0.3 second, and S_a at 1.0 second) for 162 of the 279 census tracts in the Southern Illinois study region. According to Chapter 4 of the HAZUS Technical Manual, the PGA is used to calculate the permanent ground deformation due to liquefaction, but the liquefaction susceptibility should have no effect on the ground motion parameters.

None of the 162 census tracts with reduced ground motion were predicted to have ground failure in the form of liquefaction. The PESH module increased the ground motion parameters for 61 of the census tracts in the study region. These 61 census tracts were each predicted to have ground deformation due to liquefaction. The PESH module in HAZUS did not change the ground motion parameters for the remaining 56 census tracts.

The census tracts with reduced ground motion suffered reduced damage. The green areas in the map in Figure 140 indicate the census tracts for which the ground motion was reduced, and the red areas indicate the census tracts for which the ground motion is increased when liquefaction is included in the analysis. The ground motion in the yellow census tracts remains the same.

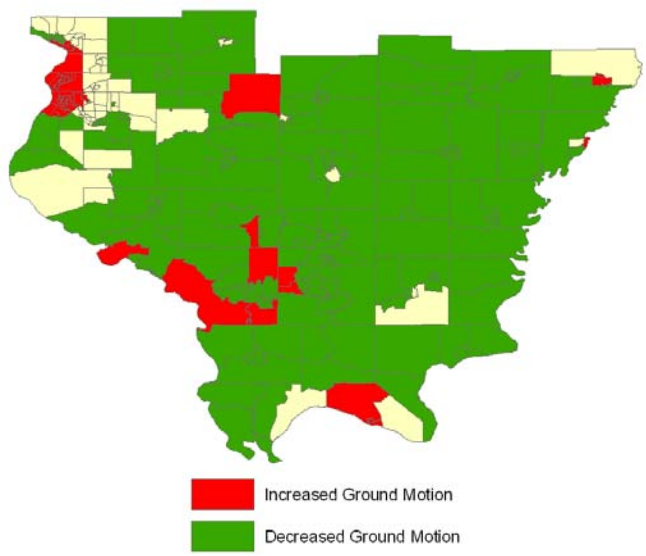


Figure 140: Ground Motion Change in Study Region Census Tracts

Because approximately 60% of the census tracts in the study region experienced no liquefaction and reduced ground motion, and an additional 20% of the census tracts experienced unchanged ground motion and no liquefaction, many of the aggregate loss estimates for the entire region were actually reduced in the case that liquefaction was included. The reduced damage results due to decreased ground motion overpowered the increased results due to liquefaction. The ground motion parameters PGA, PGV, S_a at 0.3 second, and S_a at 1.0 second are shown in the following figures.

The PGA predicted by the PESH module in HAZUS is shown for the case including liquefaction and the case without liquefaction in Figures 141 and 142, respectively.

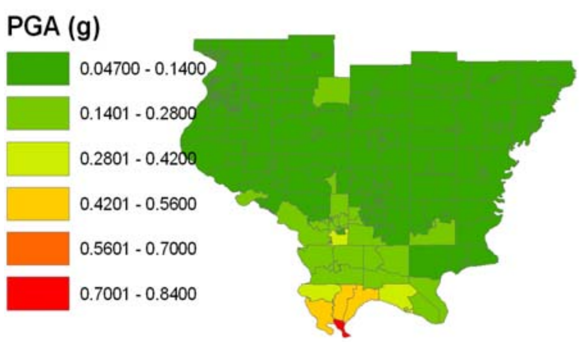


Figure 141: PGA with Liquefaction

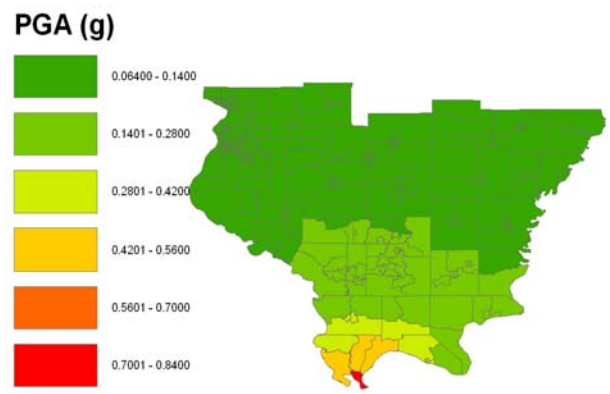
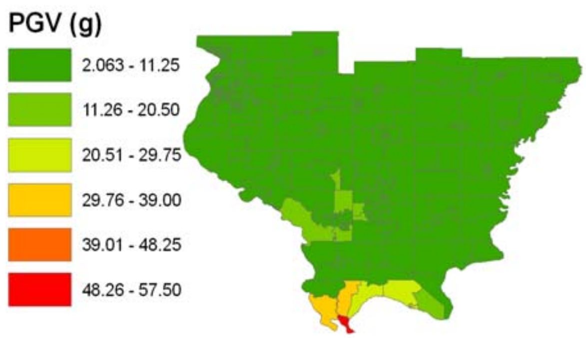


Figure 142: PGA without Liquefaction

The PGV, as predicted by HAZUS for both cases is shown in Figures 143 and 144.



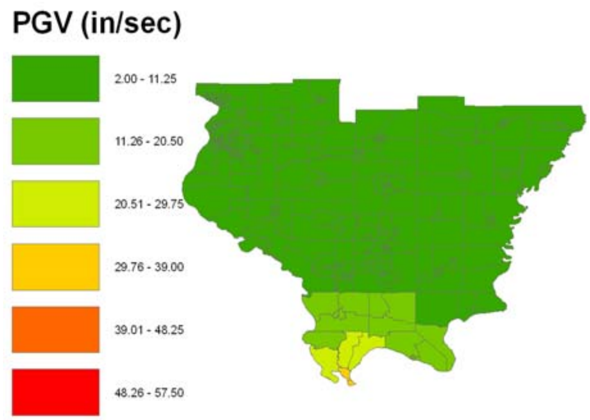
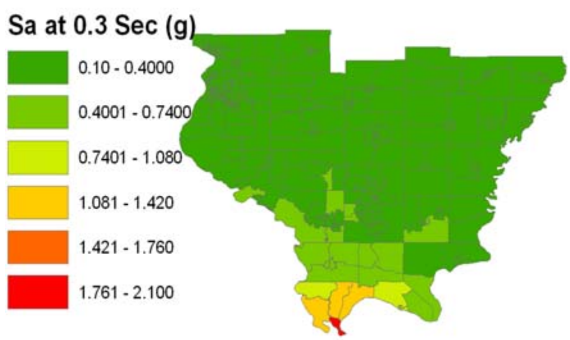


Figure 143: PGV with Liquefaction

Figure 144: PGV without Liquefaction

The spectral acceleration at 0.3 second predicted by the PESH module is shown in Figures 145 and 146 for the study region including and excluding liquefaction, respectively.



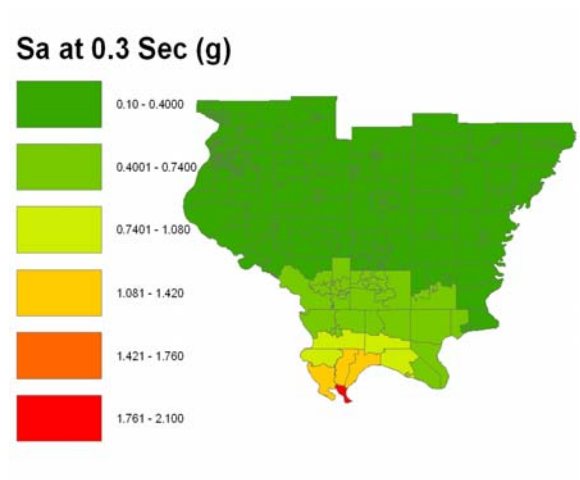


Figure 145: Sa at 0.3 Sec with Liquefaction

Figure 146: Sa at 0.3 Sec without Liquefaction

The spectral acceleration at 1.0 second, as predicted by HAZUS, is shown for the case with liquefaction and the case without liquefaction in Figures 147 and 148, respectively.

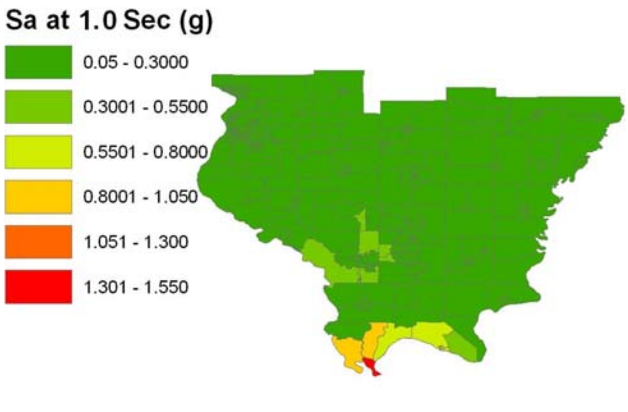


Figure 147: Sa at 1.0 Sec with Liquefaction

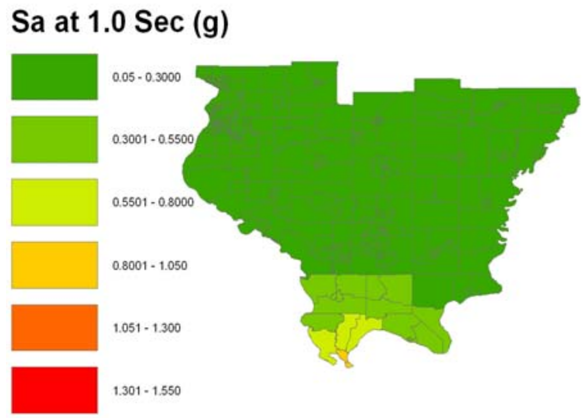


Figure 148: Sa at 1.0 Sec without Liquefaction

13.4 General Building Stock Replacement Costs

In HAZUS, the default replacement costs for residential, commercial, industrial, and institutional buildings were derived from Means Square Foot Costs 2002 for (HAZUS TM Section 5.1.12.2). The HAZUS Technical Manual states that building costs from the most current Means Square Foot Costs document can replace those from the 2002 document in the HAZUS replacement cost database. Changing the replacement costs for the general building stock in the program is not as simple as updating the costs in the database table that contains the replacement costs and then re-creating the study region using the new costs.

The replacement costs for the general building stock can be found in the table "hzReplacementCost" which is located in the "HzAnalParams.mdb" database in the "DATA" folder that is supplied with HAZUS. A sensitivity test was performed to determine the effect of changing the values in the hzReplacementCost table on the direct loss estimates for the general building stock in which the values in the table were all changed to very high values and in which all values in the table were changed to zero. The study region was re-created after the costs were changed to ensure the new replacement costs would be used in every case. Neither of these scenarios produced loss estimates that differed from the loss estimate using the default replacement costs. It was concluded that changing the values in the hzReplacementCost table does not affect the loss estimates.

It was determined by reading the documentation for the hzReplacementCost table that the replacement cost parameters are multiplied by the square footage values for each census tract for each occupancy class (hzSqFootageOccupB table) to create a table of exposed value for each occupancy class in each census tract (hzExposureOccupB table). Instead of taking the replacement costs from the hzReplacementCost table, HAZUS uses the values from the exposed value table, which gives total replacement cost for every census tract in Illinois for every occupancy class. Because the hzExposureOccupB table includes every census block in the state of Illinois for every occupancy class, so there are over 10 million cells in the table. This is much larger than what can be readily worked with to update replacement costs. It was decided that applying a cost inflator to the final direct loss value for the general building stock may be a better solution than changing individual replacement costs.

14. Summary and Conclusions

A seismic loss assessment was conducted for the State of Illinois for the purposes of determining the vulnerable infrastructure elements, prioritizing mitigation efforts in the state, quantifying damage in economic terms, and aiding in the development of public awareness projects. The study was performed using FEMA's HAZUS loss estimation software, and included several levels of analysis. First, a level 1 loss estimation was conducted using HAZUS default inventories and loss parameters but with user-supplied ground motion. Additional loss estimations were performed using site class maps to refine the ground motion, liquefaction susceptibility maps to estimate the effects of liquefaction, pipeline inventories from FEMA's HSIP Gold Dataset, improved essential facilities inventories, bridge inventories provided by IDOT, and improved building and highway bridge fragilities.

14.1 HAZUS Level 1 Analysis

The level 1 HAZUS analysis estimated that there would be over 12,000 buildings suffering extensive damage and 2,800 suffering complete damage in the general building stock. Approximately 7% of hospitals, 2% of schools, 4% of police stations, and 4% of fire stations were estimated to suffer at least moderate damage. A relatively small number of utility system facilities—less than five percent of any given utility inventory—were estimated to suffer at least moderate structural damage, and no facilities were estimated to be damaged beyond repair. It was estimated that over 10,700 households would be without electric power and over 13,000 households would be without potable water on the day of the event. Each of these totals was less than 1% of the total households in the state. HAZUS estimated that the total economic loss to buildings would be \$2.06 billion, the total to transportation systems would be \$211 million, and the loss to utility systems would be \$1.16 billion for a total direct economic loss of approximately \$3.4 billion.

14.2 Local Site Class Effects

A study was conducted in which site class effects were included for the southern portion of Illinois. The results were compared with those from an analysis of the same region with uniform site class D. The site effects caused the ground motion to decrease for a majority of census tracts in the state, so in general, the damage and loss estimates were reduced. The estimated damage to essential facilities decreased for hospitals, schools, emergency operation centers, police stations, and fire stations. The direct economic loss for the general building stock was estimated to be $2.01 billion for a uniform site class D soil condition and $1.68 billion for the southern portion of Illinois when the site class effects were included. The total economic losses to the transportation systems for the study region increased from $187 million to $207 million when site class effects were included. The transportation economic losses increased because many highway bridges and railway components lie in census tracts where the ground motion increased with site effects. The loss to the utility systems decreased for the study region decreased from $1.10 billion to $915 million. The total direct economic losses for southern Illinois assuming uniform soil D was estimated to be $3.30 dollars, and the loss including site class effects was estimated to be $2.80 billion. This represents an 18% decrease in direct economic losses. The effects of site classes were estimated for Massac County to illustrate that when the soil causes an increase in ground motion, the damage and losses also increase.

14.3 Liquefaction Effects

The effects of liquefaction on the damage and loss estimates for southern Illinois were studied. Liquefaction caused the number of general buildings estimated to suffer extensive damage to increase by a factor of 2.4. It did not significantly affect the damage to essential facilities because the majority of the facilities were not located in liquefied zones. The direct economic losses increased from $2.00 billion to

$2.66 billion for the general building stock, from $188 million to $492 million for the transportation system, and from $1.10 billion to $1.29 billion for the utility systems in the study region when liquefaction was included. The total direct economic losses for southern Illinois increased from $3.30 billion to $4.44 billion when the effects of liquefaction are added to the analysis.

14.4 Improved Inventories and Parameters

Studies were performed in which the HAZUS default inventories were improved. Improved essential facilities inventories, improved bridge inventories, and natural gas and oil pipeline inventories were imported into the loss estimation tool. Damage estimates were produced for these inventories, but dollar loss estimates were not because replacement costs were not provided in the inventory databases. In addition to improved inventories, the damage results were refined for buildings and bridges. For the general building stock, damage conversion factors were used to relate the damage probabilities output by HAZUS to estimated damage that would be produced if fragility curves using PFM (Jeong, 2006) directly replaced the HAZUS fragilities. Highway bridge fragilities developed by Nielson (2005) were directly imported into HAZUS, replacing the default HAZUS highway bridge fragility curves. The use of the bridge fragilities by Nielson significantly increased the estimated damage to highway bridges.

14.5 CUSEC Study Comparison

A HAZUS analysis for the New Madrid Seismic Zone (NMSZ) region was conducted by the Central US Earthquake Consortium (CUSEC) (Blake, 2006). The CUSEC study was compared with results from this study. The differences in damage and loss estimates were due to the fact that different earthquake epicenter locations were used in the two studies and the CUSEC study was conducted using HAZUS-MH MR1 (this study was conducted using HAZUS-MH MR2). The CUSEC study estimated that the direct economic losses would be $1.24 billion for the general building stock, $278 million for the transportation systems, and $678 million for the utility systems. This study estimated that the losses would be $2.69 billion for the general building stock, $501 million for the transportation systems, and $1.31 billion for the utility systems. The losses increase for this study because the ground motion parameters are higher in magnitude due to the nearer earthquake epicenter location.

14.6 Comparison of Losses

Table 148 tabulates the study region characteristics, hazard characteristics, and direct economic losses for the loss estimation studies discussed in this report. The level 1 HAZUS analysis for the entire State of Illinois with default inventory and parameters, but with user-defined ground motion, estimated that the total direct economic losses are expected to be approximately $3.4 billion.

The southern Illinois study region of 30 counties was used to study the effects of site classes and liquefaction on the damage and loss estimates. The direct economic losses for the region, not including the effects of liquefaction or site effects, were estimated to be approximately $3.3 billion. This estimate was reduced to $2.8 billion with the addition of soil site effects because the ground motion was reduced in most census tracts by the site effects. The estimate increased to $4.4 billion when liquefaction was included. The Massac County study was performed to illustrate that in locations that the ground motion increases, the estimated losses will also increase.

Lastly, the results of this study were compared with a study performed by CUSEC. The study region was a portion of southern Illinois containing 40 counties. The earthquake epicenter for this study was much closer to Illinois than the epicenter location used in the CUSEC study, so the losses increased from $2.2 billion to $4.5 billion.

Table 148: Overall Comparison of the Studies

Study Name	Region	Number of Counties	Ground Motion Devoloped By	Site Class Map	Liquefaction Susceptibility	Building Loss	Transportation System Loss	Utility System Loss	Total Loss
Level 1 Analysis	Entrire State of Illinois	102	MAEC	None, Uniform D	None	$2.06 B	$211 M	$1.16 B	$3.4 B
Southern IL Level I	Southern Illinois	30	MAEC	None, Uniform D	None	$2.01 B	$188 M	$1.10 B	$3.3 B
Southern IL with Soil Site Effects	Southern Illinois	30	MAEC	ISGS (Bauer, 1999)	None	$1.68 B	$208 M	$915 M	$2.8 B
Southern IL with Liquefaction	Southern Illinois	30	MAEC	None, Uniform D	FEMA (2006c)	$2.66 B	$492 M	$1.29 B	$4.4 B
Massac County Default	Massac County	1	MAEC	None, Uniform D	None	$239 M	$20 M	$79 M	$338 M
Massac County Add Site Effects	Massac County	1	MAEC	ISGS (Bauer, 1999)	None	$376 M	$39 M	$92 M	$507 M
CUSEC Analysis by FEMA	Southern Illinois	40	FEMA	FEMA-defined	FEMA (2006c)	$1.24 B	$278 M	$678 M	$2.2 B
MAEC Analysis of CUSEC Counties	Southern Illinois	40	MAEC	None, Uniform D	FEMA (2006c)	$2.69 B	$501 M	$1.31B	$4.5 B

14.6 Issues in HAZUS

Lastly, issues in the HAZUS loss estimation software were discovered during this study and are reported in Chapter 13 of this report. The problems with the loss estimation tool include issues and bugs when importing bridges and pipelines, ground motion calculations, and the ability to update the general building stock replacement costs.

14.7 Future Work

There is still much more work for the loss assessment for the State of Illinois to be performed. The hazard will be improved by importing inundation maps that will be used to estimate effects of flooding due to dam failure. Improved site class maps will be provided by the Illinois State Geological Survey and will be used to refine the ground motion estimates. Liquefaction susceptibility maps that will be more accurate than those used in this study are currently in development in the Mid-America Earthquake Center and will be used to better study the effects of liquefaction. Additional inventory improvements will be made to the HAZUS default inventory. Levee, prison, military facility, and telephone facility inventories will be imported into HAZUS, and damage and losses will be estimated with these inventories. The improved hazard, inventory, and parameters to be implemented into HAZUS in future work are:

- MAEC-developed liquefaction maps
- Refined ISGS site class maps
- Telephone facilities inventory
- Prison inventory
- Military facilities inventory
- Levee inventory and fragilities
- Inundation maps
- Estimate effects of flooding due to dam failure
- MAEC social and economic impact models

Individual counties that were determined to be critical by the Illinois Emergency Management Agency (IEMA) will be studied individually. These counties are pictured in yellow in Figure 149. HAZUS will be used to produce damage and loss estimates for each individual county. The individual county studies will aid in the determination of which counties IEMA should focus on when completing mitigation and earthquake response plans.

Figure 149: Counties to Study in Detail

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16. Appendix A: CD of Hazard, Inventory, and Parameter Files

16.1 Hazard

- **FEMA Liquefaction Susceptibility Map.mdb:** This geodatabase contains the liquefaction map extracted from the study region provided by FEMA (2006c).
- **Illinois Ground Motion Uniform Soil D.mdb:** This geodatabase contains the ground motion parameters (PGA, PGV, S_a at 0.2 second, and S_a at 1.0 second) in the form of ground motion maps. A uniform site class D was assumed.
- **Southern IL Ground Motion w ISGS Site Classes.mdb:** This geodatabase contains the ground motion parameters (PGA, PGV, S_a at 0.2 second, and S_a at 1.0 second) in the form of ground motion maps. The ISGS-provided site class map was used for soil site class effects.
- **Southern IL ISGS Site Class Map.mdb:** This geodatabase contains the soil site classes for the southern one-third of Illinois. It was provided by ISGS (Bauer, 1999).

16.2 Inventory

- **Essential Facilities**
  - **MAEC Essential Facilities Inventory Final.mdb:** This geodatabase contains the final data for the essential facilities for the southern portion of Illinois that was used in this loss assessment study.
  - **MAEC Essential Facilities Inventory Raw Data.mdb:** This database contains the raw data for the essential facilities for the

southern portion of Illinois. The inventory was provided by study performed within the MAE Center (French and Olshansky, 2000).

- **IDOT Bridges**
    - **IDOT Bridge Inventory Final.mdb:** This geodatabase contains the final bridge data for locally and state maintained bridges that were used in the study.
    - **IDOT Locally Maintained Bridge Inventory Raw Data.xls:** This workbook contains the raw locally maintained bridge inventory data, as provided by IDOT (Ahrens, 2006).
    - **IDOT State Maintained Bridge Inventory Raw Data.xls:** This workbook contains the raw state maintained bridge inventory data, as provided by IDOT (Ahrens, 2006).

- **Pipelines**
    - **Illinois Pipelines Inventory Final.mdb:** This geodatabase contains the natural gas and oil pipelines for the State of Illinois. The pipelines were taken from FEMA's HSIP Gold Dataset (Office of Americas/North America & Homeland Security Division, 2005).

16.3 Fragility Parameters

- **Bridge Fragilities**
    - **MAEC Bridge Fragility Parameters.xls:** This worksheet contains bridge fragilities developed by the MAE Center. The parameters were input directly into HAZUS.

- **Building Fragilities**
    - **GBS HAZUS to PFM Damage Conversion Factors.xls:** This workbook calculates the probability of exceeding a given limit state as calculated using PFM divided by the probability calculated by HAZUS for the

general building stock. These ratios were used to modify the damage probabilities output by HAZUS.

- **GBS HAZUS to PFM Damage Conversion.xls:** This workbook multiplies the GBS fragility conversion factors, which are calculated in "GBS HAZUS to PFM Fragility Conversion Factors.xls" by the probabilities of damage output by HAZUS for the general building stock in the State of Illinois. The result is modified damage estimates to better reflect PFM fragilities.

- **Parameterized Fragilities Using HAZUS Pushover and LSs.xls:** This workbook contains the fragility parameters (λ and β) for the PFM fragilities derived in the MAE Center.