Comparison Study of the 1985 CUSEC Six Cities Study Using HAZUS

Prepared by

The Central United States Earthquake Consortium

July 2003

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HAZUS Comparison Study of 1985 CUSEC Six Cities Study

Background: Since 1985 when the original six cities study was done, three major changes have taken place which affects any future comparative runs. One, the Wabash Valley Seismic zone has been more defined as a seismic zone capable of producing large damaging earthquake in the magnitude 7 range. This could have a more dramatic effect on Carbondale, Evansville, and Paducah than an event along the New Madrid which was not addressed in the original study.

The second significant change is with the scenario events of 7.6 and 8.6 which were used. Scientific studies since 1985 have adjusted the maximum credible earthquake for this region and have determined a 6.5 and 7.5 to be a more accurate representation, although the level of shaking is still believed to be comparable to larger events. Also, the original study used epicenters closest to the city that did not have definable latitude and longitude coordinates. In the comparison study, historical epicenters associated with the 1811-1812 New Madrid seismic events were used.

Third, the population of the central United States as whole has changed considerably due to increased population and building stock. This has the possibility of placing more risk on the region.

Project: Perform a Level One HAZUS analysis of the six cities investigated in the original 1985 study by Allen and Hoshall for FEMA, namely, Little Rock, AR, Carbondale, IL, Evansville, IN, Paducah, KY, Poplar Bluff, MO, and Memphis, TN.

At a minimum, source events of intensity, M=6.5 and 7.5, using historic epicenters from the 1811-1812 New Madrid events, will be considered for each of the six cities. Furthermore, a source event of intensity, M=7, with epicenter in the Wabash Valley seismic zone, will be considered for Carbondale, Evansville, and Paducah.

Deliverables: Deliverables will include this report which identifies:

1) assumptions in the model relating to the source events considered and soil conditions (e.g. saturated or dry) if possible
2) authors
3) findings for the six communities in the areas of:
    a) Casualties
    b) Transportation systems
    c) Utility systems
    d) Critical facilities (hospitals, fire stations, police stations, and schools)
    e) Shelter requirements
    f) Estimated restoration and replacement costs

A comparison of relative loss potential between New Madrid and Wabash Valley seismic zones for Carbondale, Evansville, and Paducah.

The comparisons will be made on the basis of categories in the original study to the extent permissible, given the different nature of some of the HAZUS categories and the organization of the HAZUS database by county and census tract rather than municipal boundaries.

Original Six Cities Study

In 1985, the Central United States Earthquake Preparedness Project (CUSEPP), originally created by FEMA, had the responsibility of helping the CUSEC states in planning, preparedness and mitigation, response, and recovery. One of the projects of CUSEPP was "An Assessment of Damage and Casualties for Six Cities in the Central United States Resulting from Earthquakes in the New Madrid Seismic Zone" report. This report was prepared for FEMA by Allen & Hoshall, Inc., an engineering and architecture firm in Memphis, Tennessee. The study provided two earthquakes scenarios having surface magnitudes (Ms) of 7.6 and 8.6 and provided loss estimation for the cities: Little Rock, Arkansas; Carbondale, Illinois; Evansville, Indiana; Paducah, Kentucky; Poplar Bluff, Missouri; and Memphis, Tennessee. A similar report was compiled for St. Louis in 1990, which is contained in FEMA publication 192.

The original six cities were chosen by the following criteria-

- Population size in relation to area of damage vulnerability
- Architectural types
- Cooperation of cities to be studied

Furthermore, only urbanized areas within incorporated city limits were studied in the report. As previously stated, surface magnitudes of 7.6 and 8.6 were used in the report with the epicenter of the earthquake "located as close to each city as possible within the entire New Madrid Seismic Zone". The two scenarios were chosen because the 8.6 Ms event had a catastrophic damage potential and the 7.6 Ms event was an event with a higher probability of occurrence. The study made the realistic statement that an earthquake in the New Madrid Seismic Zone, of either determined size, would cause a large amount of damages, deaths, and injuries on a scale never seen before by a natural disaster in the region.

The report used the following methods and procedures to estimate the effects of earthquakes in the New Madrid Seismic Zone-

- Collection of structural inventory and critical facility data
- Used assistance from the U.S. Geological Survey in determining levels of ground shaking

- Development of fragility curves for structures in the six cities

The effects of an earthquake in the area would have varying effects from city to city, according to the report. The following common effects were looked at in the study and the probable consequences were provided-

- Casualties (deaths and injuries)
- Medical Facilities
- Transportation Systems
- Utility Systems
- Critical Facilities
- Flooding
- Fires
- Shelter Requirements

The original six cities study was an important report because it provided a quantitative assessment, for the first time, that a large earthquake could impact the New Madrid Seismic Zone with "widespread disruption, damage, and casualties". Furthermore, the economic impact of a large earthquake would be staggering at the least. The central United States is the coordinating hub through which most domestic products pass through en-route to their final destination. The report showed that the central United States, in the event of a large, 1811-1812 scale earthquake, would be dependant on outside assistance in all the categories of the study.

Introduction to HAZUS [1]

As part of its efforts to mitigate hazards and protect lives and property from the devastating effects of natural disasters, FEMA aims to provide individuals, businesses, and communities with information and tools to work proactively to mitigate hazards and prevent losses resulting from disasters. One of these tools is HAZUS or Hazards U.S., a natural hazard loss estimation methodology developed by FEMA under contract with the National Institute of Building Sciences.

Using Geographic Information Systems (GIS) technology, HAZUS allows users to compute estimates of damage and losses that could result from an earthquake. To support FEMA's mitigation and emergency preparedness efforts, HAZUS is being expanded into HAZUS-MH, a multi-hazard methodology with new modules for estimating potential losses from wind and flood hazards.

[1] FEMA Web Site, 2003: http://www.fema.gov/hazus/hz_index.shtm

Earthquakes & HAZUS [2]

The Earthquake Loss Estimation Methodology Study was conducted by the National Institute of Building Sciences and sponsored by FEMA as part of its leadership role under the National Earthquake Hazards Reduction Program (NEHRP). The NEHRP is the Federal government's program to address the nation's earthquake threat. Under the program, the government seeks to answer two basic questions: how earthquakes will affect the nation and how best to apply our resources to reduce earthquake's impacts.

An eight member Project Work Group (PWG) consisting of earthquake experts chaired by Robert Whitman, a professor of civil engineering at the Massachusetts Institute of Technology, provided technical oversight and a 15 member Project Oversight Committee (POC), in which CUSEC was a member of, and was chaired by Henry Lagorio, a professor of architecture at the University of California at Berkeley, represented user interests in the earthquake community and provides user/client input. Over 75 POC corresponding members representing user and technical interests reviewed drafts of project reports. In 1993, the PWG and POC defined the components of the loss estimation methodology, prepared an extensive set of objectives for developing the methodology, and generated a standardized list of earthquake caused economic and social losses as methodology outputs.

Three major earthquake-engineering firms were responsible for accomplishing project tasks. Risk Management Solutions, Inc., of Menlo Park, CA, developed and calibrated the methodology; Dames & Moore of Seattle, WA, initiated the first pilot study of the methodology for Portland, OR, in early 1995, the final report was delivered in January 1997; and EQE International initiated a second in Boston, MA, in early 1996, the final report was delivered in fall 1997. Collection of inventory data and preparation of preliminary and final damage and loss reports based on two scenario earthquakes were completed for both pilot studies.

The study, initiated in October 1992, began with an assessment of the existing earthquake loss methodologies. The task was completed in 1993, and a report entitled "Assessment of the State of the Art Earthquake Loss Estimation Methodologies" was published by FEMA in spring of 1994. This report reflects a comprehensive survey of literature identifying studies relevant to loss estimation, an evaluation of the potential of existing studies for use in developing the standardized loss estimation methodology, and identification of gaps in current loss estimation technology. Work on the first task was performed by a joint venture between Risk Management Solutions, Inc. (RMS), and the California Universities for Research in Earthquake Engineering (CUREE).

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[2] FEMA Web Site, 2003: http://www.fema.gov/hazus/hs_eqdev.shtm

Between the end of 1993 and the end of 1994, the earthquake loss estimation methodology was developed including the following: categorization of building and infrastructure inventory; estimations of potential earthquake hazard, seismic damage to buildings and lifelines, and induced damage from floods, fire and hazardous material release; and estimations of social and economic losses. A beta release of HAZUS, supporting software in GIS format based on MapInfo, and drafts of a technical manual for use in performing loss estimations and a user's manual to explain the methodology to local, state, and regional officials and other users were also completed.

As a major feature of HAZUS, an inventory data collection module was developed to provide guidance to emergency managers, planners and local officials in collecting inventory data required for regional multi-hazard (earthquake, hurricane, flood and tornado) loss estimation. Methodology calibrations utilizing existing literature and damage data from Northridge, Loma Prieta, and other previous earthquakes were conducted by RMS between 1994 and 1997. Pilot testing of the inventory data collection module was conducted by the California Office of Emergency Services (OES) in the East Bay (Oakland) region and by the U.S. Army Corps of Engineers for select military bases.

Although the earthquake methodology has been completed, improvements and updates will continue under the guidance of an expanded PWG, now called the Earthquake Committee.

A single standardized approach for estimating earthquake (and in the future wind and flood) losses will allow state and local governments to work more effectively with the Federal agencies. By collecting and analyzing data using a consistent method, it will be possible to predict the level of resources needed more accurately and to more effectively allocate available resources.

HAZUS Loss Estimates[3]

What is a HAZUS Earthquake Loss Estimate?
Earthquake loss estimates are forecasts of damage and human and economic impacts that may result from future earthquakes. These are estimates based on current scientific and engineering knowledge.

The FEMA HAZUS earthquake loss estimation methodology is a software program that uses mathematical formulas and information about building stock, local geology and the location and size of potential earthquakes, economic data, and other information to estimate losses from a potential earthquake. HAZUS is capable of using two separate geographic information systems (MapInfo™ and ArcView™) to map and display ground shaking, the pattern of building damage, and demographic information about a community. Once the location and size of a

[3] FEMA Web Site, 2003: http://www.fema.gov/hazus/eq_est.shtm

hypothetical earthquake is identified, HAZUS will estimate the violence of the following:

- ground shaking
- the number of buildings damaged
- the number of casualties
- the amount of damage to transportation systems
- disruption to the electrical and water utilities
- the number of people displaced from their homes
- estimated cost of repairing projected damage and other effects

Why Do I Need to Estimate Earthquake Losses?
An estimate of losses from future earthquakes is essential to preparing for a disaster and facilitating good decision making at the local, regional, state, and national levels of government. A HAZUS estimate of earthquake losses provides vital tools for the following:

- Land-use planning and facility siting decisions (e.g., a map-based analysis of the potential intensity of ground shaking from a postulated earthquake that identifies those parts of the community that will experience the most violent shaking and the buildings at greatest risk of damage).
- Prioritization of retrofit or abatement programs (e.g., an estimate of building damage that provides the basis for establishing programs to mitigate or strengthen buildings that may collapse in earthquakes by providing estimates of damages and casualties).
- Regional, state, and local emergency response and contingency planning (e.g., estimates of casualties and of damage to buildings and utilities).
- Medical and relief agency preparedness and response (e.g., estimates of casualties and homelessness).
- Assistance planning (e.g., an estimate of dollar losses that will help the state and federal governments plan for assistance to jurisdictions and disaster victims).

How Do I Use HAZUS to Prepare for Earthquakes?
The first step in preparing for a disaster is estimating its potential impact. Loss estimates can provide the basis for developing mitigation policy, for developing and testing emergency preparedness and response plans, and for planning for post disaster relief and recovery.

- ***Before an Earthquake: Mitigating Future Losses***
  Reducing earthquake losses begins before the earthquake. Loss estimates provide public and private sector agencies with a basis for planning, zoning, building codes and development regulations, and policy that would reduce the risk posed by violent ground shaking and ground failure. Loss estimates can also be used to evaluate the cost effectiveness

of alternative approaches to strengthening potentially hazardous structures.

- ***Before an Earthquake: Preparing to Respond***
  Understanding the scope and complexity of earthquake damage is essential to effective preparedness. HAZUS can forecast damage to buildings, casualties, and disruption of utilities. These estimates can be the basis for developing emergency response plans and for organizing tests and exercises of response capability.
- ***"A Guide to Using HAZUS for Mitigation"*** describes how HAZUS can help your local community, county, region or state identify, develop and implement measures to accomplish effective earthquake hazard risk reduction. Download the Guide
- ***After an Earthquake: Speeding Response and Relief***
  A rapid response to a damaging earthquake will reduce loss of life, complications from injuries and secondary damage and loss, and will expedite relief to victims.

  HAZUS can be an important decision support tool during this response period. Immediately after a damaging earthquake, HAZUS can help emergency managers identify the likely damaged areas, provide a rapid estimate of the damage and casualties that occurred and the type and amount of resources that should be deployed to assist the affected area.

Response and relief agencies can use HAZUS to project damage, loss, and the number of homeless and to estimate the financial and material resources necessary to assist victims. Regional, state, and federal officials can use HAZUS estimates of casualties and injuries to project demand on medical resources. Utilities can use HAZUS estimates and the projected pattern of power and water outages to organize and set priorities for recovery.

What Information Do I Need to Provide HAZUS?
Data requirements for HAZUS will vary with the level of accuracy desired, the data available about the community, and how much can be invested in a loss estimate. There are three estimation levels that can be produced using HAZUS software:

- ***When Would I Perform a Level One Analysis?***
  All of the information you will need to produce a preliminary estimate of losses from an earthquake is included in the HAZUS software. This data from national databases included in HAZUS describes in general terms the geology of the region and the building inventory and economic structure of the community. The national data is used to provide a Level One estimate of losses.
- ***When Would I Perform a Level Two Analysis?***
  More accurate estimates of losses require more detailed information about

the community. To produce a Level Two estimate of losses, detailed information will be required about local geology, an inventory of buildings in the community, and data about utilities and transportation systems. Assistance from geotechnical and structural engineers may be necessary for this analysis.

- ***When Would I Perform a Level Three Analysis?***
  The most accurate estimate of loss will require detailed engineering and geotechnical input to customize the methodology to the specific conditions of the community.

  Level One and Level Two studies can typically be carried out by local government emergency services or planning staffs; Level Three estimates require assistance from structural engineers and geologists.

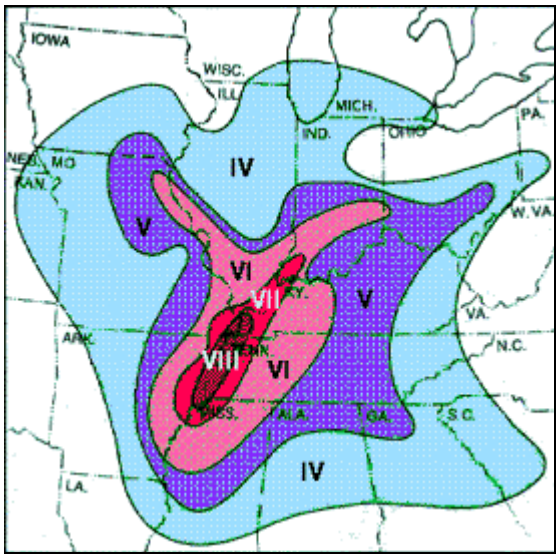
How Does HAZUS Calculate Losses?
HAZUS uses Geographic Information System (GIS) software and scientifically developed algorithms to calculate, map, and display earthquake loss data.

Once the size and location (epicenter) of a hypothetical earthquake is selected, the HAZUS software, using a series of mathematical formulas, calculates the violence of ground shaking, the amount of damage, the number of casualties, the number of people displaced by damaged structures, and the disruption and economic losses caused by the earthquake. These formulas describe the relationship between earthquake magnitude, violence of ground shaking, building and utility system damage, cost of repair, and indirect economic impact. HAZUS allows for changing the size and location of the hypothetical earthquake to see the range of damage that may occur to the community.

What Will a HAZUS Earthquake Loss Estimate Cost?
The exact cost of using HAZUS is determined by user needs and the availability of data. The basic components include a computer system, the HAZUS software, GIS software, other data (additional/local), and engineering and technical expertise. The cost of an estimate varies depending on the estimation level (One, Two, or Three) being performed, the availability of inventory data, the computer system available, and the necessity and availability of technical expertise. To run a Level One estimate, all that is required is the computer system described in the section, "Requirements for Running HAZUS", the GIS software, and the HAZUS software. The 1999 version of the HAZUS software is currently available at no cost. MapInfo™ or ArcView™ must be purchased by the user. Level Two and Level Three estimates require both detailed data and engineering and geotechnical expertise. In addition to hardware and software costs, approximately one day of staff time would be necessary to produce a Level One analysis for a community; more time would be required for deeper levels of analysis.

New Madrid Seismic Zone[4]

The earthquakes of 1811-1812 that occurred near New Madrid, Missouri, are some of the strongest earthquakes to strike domestic soil in United States history. The earthquakes occurred in an area that is known as the New Madrid Seismic Zone, and to date, this seismic zone continues to be active. The new Madrid Seismic Zone is located in the central U.S. from Cairo, Illinois to Marked Tree Arkansas. However, the impacts of an earthquake in the region are far reaching. The following map depicts the possible impact that a magnitude 8 earthquake would have on the region.



The loss of life and destruction in recent earthquakes of only moderate magnitude (for example, 33 lives and $20 billion in the 1994 magnitude-6.7 Northridge, California, earthquake and 5,500 lives and $100 billion in the 1995 magnitude-6.9 Kobe, Japan, earthquake) dramatically emphasize the need for residents of the central United States to prepare further for an earthquake of such magnitude. Earthquakes of moderate magnitude occur much more frequently than powerful earthquakes of magnitude 8 to 9; the probability of a moderate earthquake occurring in the New Madrid seismic zone in the near future is high. Scientists estimate that the probability of a magnitude 6 to 7 earthquake occurring in this seismic zone within the next 50 years is higher than 90%. Such an earthquake could hit the central United States at any time.

In 1811, the central Mississippi Valley was sparsely populated. Today, the region is home to millions of people, including those in the cities of St. Louis, Missouri, and Memphis, Tennessee. Adding to the danger, most structures in the region were not built to withstand earthquake shaking, as they have been in more

[4] U.S. Geological Survey Fact Sheet-168-95; 1995

seismically active areas like California. Moreover; earthquake preparations also have lagged far behind.

Strong earthquakes in the New Madrid seismic zone are certain to occur in the future. In contrast to the western United States the causes and effects of earthquakes in the central and eastern United States are just beginning to be understood. Through better understanding of earthquake hazards and through public education, earth scientists and engineers are helping to protect the citizens of all parts the United States from loss of life and property in future earthquakes.

Wabash River Valley Seismic Zone

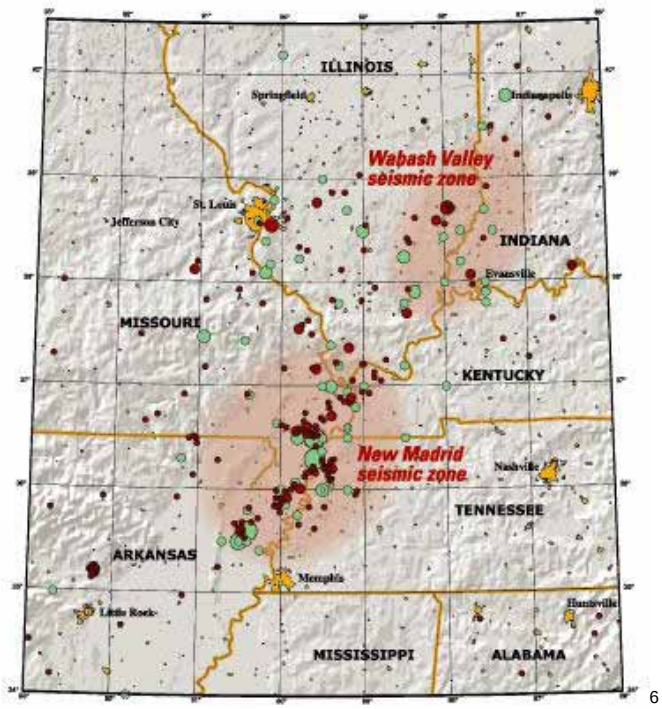
When the original six cities study was completed, the Wabash River Valley Seismic Zone located in Southeastern Illinois and Southwestern Indiana was not included in the report. Since the discovery of this seismic zone, earthquake awareness and preparedness have increased, as moderate sized earthquakes have struck the area. On June 18, 2002, a 5.0 magnitude earthquake struck the Evansville, Indiana with an epicenter between Mt. Vernon and West Franklin in Posey County. According to the Indiana University Indiana Geological Survey, while there was minor damage associated with the earthquake, the tremor was a warning to residents of the Wabash River Valley Seismic Zone that earthquakes can, and do, strike close to home. Geologists in Indiana and Illinois have found liquefaction sites and sand dikes that shows the evidence of prehistoric earthquakes in the region. By examining the size of the dikes and sediment found within the sand dikes, geologists are able to estimate the size of the earthquake it took to create the formations. In the mid-1980's, geologist Steven Obermeier found a liquefaction formation that was estimated, through carbon dating, to be 6,100 years old. The earthquake that produced the site was estimated to be a magnitude 7.0, large enough to seriously disrupt the area known as the Wabash River Valley Seismic Zone.

For these reasons, when performing this study, it was deemed essential to include an event, such as the 7.0 event found by Obermeier, in the analysis. The cities from the original six cities study that would be most impacted by an event in this region are: Carbondale, Illinois; Evansville, Indiana, and Paducah, Kentucky. These cities were included in the New Madrid Seismic Zone HAZUS analysis, as well.

According to the USGS[5], this map of the New Madrid and Wabash Valley seismic zones shows earthquakes as circles. Red circles indicate earthquakes that occurred from 1974 to 2002 with magnitudes larger than 2.5 located using modern instruments (University of Memphis). Green circles denote earthquakes

[5]USGS Website: http://pubs.usgs.gov/fs/fs-131-02/fs-131-02.html

that occurred prior to 1974 (USGS Professional Paper 1527). Larger earthquakes are represented by larger circles.



[6]

Assumptions in the Update

When performing a level one HAZUS loss estimate for the six cities, it is important to look at several things within HAZUS to gain a better understanding of the final analysis.

First, HAZUS uses census tract data when creating a study region. The tracts are as defined from the 1990 census. Using the census tracts, as opposed to county regions, allows the user to define a small study region, if necessary. In the original six cities study, the "city limits" of each city was used as the study region boundaries. While there were no geographical coordinates to go by in the study, when performing this update, with assistance from the Government Publications Library at the University of Memphis, the *2000 Census Tract Outline Maps* were used to define the "city limits". Some of the census tracts in these maps overlap areas that are not incorporated, but in these cases, the census tract in question had to be included in the analysis to be inclusive of the study region.

A level one HAZUS run is a default analysis with only hazard specific data, or event parameters, (epicenter, magnitude, depth, etc) input by the user. In this six city analysis, no data was input into HAZUS, with the exception of event

[6]USGS Website: http://pubs.usgs.gov/fs/fs-131-02/fs-131-02.html

parameters. The current release of HAZUS uses 1990 census data. This census data is accurate in some levels, but in others it is not. For instance, it is difficult for the census data to contain the entire building inventory in a study region. By doing a mass data collection of inventory, one would be able to "fine tune" the HAZUS inventory to the study region in question, producing a level two analysis. For a study region as large and inclusive as this, it would possibly take teams of data collectors and months, if not years of inventory collection. For small towns and cities, the data collection and input could be done with relative ease. Some planning departments in Tennessee are using handheld Global Positioning System (GPS) devices to capture and input field data from daily routes to assist in the data collection process. In a level one analysis, the soil type and condition (saturated or dry) are unchanged, so it is possible that soil types in the current study regions are not 100% accurate. Only through gaining accurate soil data and manipulating the database for each region, would this be possible. This type of input would result in a level two analysis, but again would require large quantities of time and manpower to input the data necessary.

Next, when performing a loss estimation using HAZUS, it is necessary to create a scenario, or event, that will be used to determine the type and scope of the event. In the original six cities study, earthquakes with epicenters in the New Madrid Seismic Zone at the location closest to each city were used as models. In this comparison, historical epicenters were used. For the cities in the New Madrid Seismic Zone (all the six cities), the famous December 16, 1811 epicenter was used. This earthquake was the first in a series of earthquakes that rocked the central United States for several months. Magnitude 6.5 and 7.5 earthquakes were used for the analysis. The magnitude 6.5 represents a higher probability of reoccurrence and the magnitude 7.5 represents a higher damage potential event. For Carbondale, Evansville, and Paducah, located in the Wabash River Valley Seismic Zone, the historical earthquake from April 27, 1925 event was used, in addition to the New Madrid events of 1811. This epicenter was near Princeton, Indiana and was felt in Indiana, Illinois, Missouri, Kentucky, and Ohio. Magnitude 7.0 was used for the Wabash event, which represents the type of earthquake that Obermeier discovered through liquefaction sites in the mid-1980s. The depth of the earthquakes for this analysis was left at the default HAZUS depth of 10 kilometers.

After study region and event scenarios have been created in HAZUS, the analysis can be performed. HAZUS goes through a vast series of scripts, algorithms, and calculations to bring the final analysis together. Once the event has been "run", HAZUS can display event damage by building type, casualty rate, critical facilities, and many other categories. A useful tool of the final analysis is the Global Summary Report that is automatically generated. There are individual reports for each of the HAZUS categories, but the GSR combines these categories into a 17 page, polished report. The GSR is not without its own limitations, however. The reports can display incorrect numbers or percentages that are not formatted correctly. For instance, the building inventory damage

report may state that “of the 1,000 buildings in the region, 250 would be moderately damaged. This is about 2,500% of the total building stock”. Obviously, the correct statement is “…about 25% of the total building stock”. HAZUS users have reported these errors to HAZUS programmers, and in the new HAZUS-MH, to be released in fall of 2003, the errors should be corrected.

When given these parameters, it is highly probable to say that the analysis that HAZUS returns is not 100% accurate, but rather a best guess. It is impossible to know exactly how many buildings will fall, people that will perish, or the exact restoration costs *before* a disaster occurs. With that in mind, the original six cities study and the comparison of that study using HAZUS are meant to shed light for emergency managers, planners, and government officials to the possible impacts that an earthquake could bring the central United States. Whether viewing the analysis results pre-event or comparing them, post-event, it is paramount to remember that the analysis is a loss estimation tool, not a standard for what will, or will not occur. There is no way possible, at this time, to predict what Mother Nature will bring to the table, but by using tools such as HAZUS, communities can get a look into what actions need to be taken to further prepare for natural *and* manmade disasters.

Original Six Cities Study Estimations

This section includes the original loss estimate tables from the 1985 study. These tables can be used as a benchmark and to compare the original version to the updated estimates from HAZUS located in the Global Summary Reports. Note that for transportation systems and some critical facilities, tables were not included in the original study, only probability charts.

Casualties

Total Estimated Deaths Due to Structural Failure: Ms = 7.6 Event			
City	*Night*	*Day*	*School Deaths as % of Day Deaths*
Memphis, TN	211	2523	26
Paducah, KY	47	116	18
Carbondale, IL	29	74	30
Evansville, IN	23	227	32
Poplar Bluff, MO	1	17	88
Little Rock, AR	3	64	16
Total	**314**	**3021**	**26 (avg.)**

Total Estimated Deaths Due to Structural Failure: Ms = 8.6 Event			
City	*Night*	*Day*	*School Deaths as % of Day Deaths*
Memphis, TN	435	3786	27
Paducah, KY	101	201	19
Carbondale, IL	69	160	25
Evansville, IN	58	492	32
Poplar Bluff, MO	4	52	81
Little Rock, AR	9	216	17
Total	**676**	**4907**	**27 (avg.)**

Medical Facilities

Hospital Beds Estimated to be Available: Ms = 7.6 Event			
City	*Hospitals Structures Surveyed*	*Number*	*% of Total Beds Available*
Memphis, TN	25	3230	52
Paducah, KY	7	720	89
Carbondale, IL	20	2020	90
Evansville, IN	7	690	90
Poplar Bluff, MO	6	190	95
Little Rock, AR	13	3760	100
Total	**78**	**10,610**	**86 (avg.)**

Hospital Beds Estimated to be Available: Ms = 8.6 Event			
City	*Hospitals Structures Surveyed*	*Number*	*% of Total Beds Available*
Memphis, TN	25	2290	37
Paducah, KY	7	600	74
Carbondale, IL	20	1620	72
Evansville, IN	7	590	77
Poplar Bluff, MO	6	160	79
Little Rock, AR	13	3720	99
Total	**78**	**8980**	**73 (avg.)**

Utility Systems

Estimated Availability of Utility Systems: Ms = 7.6 Event				
City	*Electric*	*Water*	*Gas*	*Sewer*
Memphis, TN	U	U	U	M*
Little Rock, AR	U*	A	M	A
Evansville, IN	U	U	U	U
Paducah, KY	U	U	U	U
Carbondale, IL	U	U	U	U
Poplar Bluff, MO	U	U	U	U

U = System likely to be unavailable
M = System may be available
A = System likely to be available
* = Limited and/or modified use possible

All systems are expected to be unavailable for the Ms=8.6 event.

Shelter Requirements

Persons Likely to Require Shelter (Due to Damage to Residence)			
City	*Due to Flooding*	*Ms = 7.6 Event*	*Ms = 8.6 Event*
Memphis, TN	10,100	231,680	353,800
Little Rock, AR	3,500	2,440	21,700
Evansville, IN	24,600	11,095	38,900
Paducah, KY	5,000	13,318	22,600
Carbondale, IL	-	5,728	11,100
Poplar Bluff, MO	-	5,743	10,600
Total	**43,200**	**270,004**	**458,700**

Estimated Restoration/Replacement Costs

Estimated Restoration/Replacement Costs (Millions of Dollars) Ms = 7.6 Event			
City	*Structures*	*Utilities*	*Total*
Memphis, TN	$22,095	$2,908	$25,003
Little Rock, AR	1,463	454	1,917
Evansville, IN	4,781	360	5,141
Paducah, KY	3,002	1,395	4,397
Carbondale, IL	809	257	1,066
Poplar Bluff, MO	558	135	693
Total	**$32,708.00**	**$5,509.00**	**$38,217.00**

Estimated Restoration/Replacement Costs (Millions of Dollars) Ms = 8.6 Event			
City	*Structures*	*Utilities*	*Total*
Memphis, TN	$27,609	$4,071	$31,680
Little Rock, AR	2,886	955	3,841
Evansville, IN	7,395	595	7,990
Paducah, KY	3,846	1,952	5,798
Carbondale, IL	1,185	387	1,572
Poplar Bluff, MO	858	217	1,075
Total	**$43,779.00**	**$8,177.00**	**$51,956.00**

Comparison of New Madrid and Wabash Valley

In this section, a comparison of relative loss potential between New Madrid Seismic Zone Events and a Wabash River Valley Seismic Zone Event for the six cities will be examined. Below, tables will summarize the different categories for a 6.5 event and 7.5 New Madrid Event and a 7.0 Wabash Valley Event. The purpose of this comparison is to see the differences in losses now that scientists have identified that the Wabash River Valley Seismic Zone is an addition to the region's seismic activity. Note that Memphis, Little Rock, and Poplar Bluff are not included in the Wabash portion of the tables.

Casualties

HAZUS has four levels of Casualties:

1) Injuries will require medical attention, but hospitalization is not required
2) Injuries require hospitalization, but are not life-threatening
3) Injuries require hospitalization, and can become life threatening if not immediately treated
4) Victims are killed by the earthquake

In HAZUS, casualties are calculated at 2 AM, 2 PM, and 5 PM to look at the different times of day that an earthquake can occur. For these tables, the totals of the 2 PM event are included. For breakdown of the other times, see the Global Summary Reports for breakdown of casualties vs. time of day.

Level 1 Casualties			
City	*6.5 M New Madrid*	*7.5 M New Madrid*	*7.0 M Wabash*
Memphis, TN	303	2,787	n/a
Little Rock, AR	13	395	n/a
Poplar Bluff, MO	12	205	n/a
Carbondale, IL	5	114	50
Evansville, IN	4	91	1615
Paducah, KY	11	156	69

Level 2 Casualties			
City	*6.5 M New Madrid*	*7.5 M New Madrid*	*7.0 M Wabash*
Memphis, TN	43	653	n/a
Little Rock, AR	1	76	n/a
Poplar Bluff, MO	2	54	n/a
Carbondale, IL	0	25	9
Evansville, IN	0	17	443
Paducah, KY	1	31	12

Level 3 Casualties			
City	*6.5 M New Madrid*	*7.5 M New Madrid*	*7.0 M Wabash*
Memphis, TN	4	91	n/a
Little Rock, AR	0	8	n/a
Poplar Bluff, MO	0	8	n/a
Carbondale, IL	0	3	1
Evansville, IN	0	2	66
Paducah, KY	0	4	1

Level 4 Casualties			
City	*6.5 M New Madrid*	*7.5 M New Madrid*	*7.0 M Wabash*
Memphis, TN	7	170	n/a
Little Rock, AR	0	15	n/a
Poplar Bluff, MO	0	16	n//a
Carbondale, IL	0	6	2
Evansville, IN	0	4	129
Paducah, KY	0	7	2

Transportation Systems

In HAZUS, transportation systems include Highways, Railways, Bus, Ferry, Ports, and Airports. These include roads, bridges, tunnels, and facilities for these systems, as well. For a complete breakdown of damage by system type, see the Global Summary Reports for each event. The following tables show the event

type, number of transportation systems, and number of systems with moderate or complete damage.

Expected Damage to Memphis, TN Transportation Systems			
Event	*Total Trans. System*	*At Least Moderate Damage*	*With Complete Damage*
6.5 New Madrid	491	27	6
7.5 New Madrid	491	98	31

Expected Damage to Little Rock, AR Transportation Systems			
Event	*Total Trans. System*	*At Least Moderate Damage*	*With Complete Damage*
6.5 New Madrid	369	0	0
7.5 New Madrid	369	12	1

Expected Damage to Poplar Bluff, MO Transportation Systems			
Event	*Total Trans. System*	*At Least Moderate Damage*	*With Complete Damage*
6.5 New Madrid	37	0	0
7.5 New Madrid	37	3	1

Expected Damage to Carbondale, IL Transportation Systems			
Event	*Total Trans. System*	*At Least Moderate Damage*	*With Complete Damage*
6.5 New Madrid	56	0	0
7.5 New Madrid	56	4	0
7.0 Wabash	56	2	0

Expected Damage to Evansville, IN Transportation Systems			
Event	*Total Trans. System*	*At Least Moderate Damage*	*With Complete Damage*
6.5 New Madrid	78	0	0
7.5 New Madrid	78	1	0
7.0 Wabash	78	13	3

Expected Damage to Paducah, KY Transportation Systems

Event	*Total Trans. System*	*At Least Moderate Damage*	*With Complete Damage*
6.5 New Madrid	120	0	0
7.5 New Madrid	120	2	0
7.0 Wabash	120	1	0

Utility Systems

In HAZUS, loss of electricity and water is drawn from total number of households. The following tables show event type, total households, number of households with out water and number of households without electricity. Both are considered at day one of the event. For a complete breakdown of damage by utility type and facility, see the Global Summary Report for each city. Note that HAZUS estimates that the most damage to utility systems will be in Evansville, IN, from the 7.0 Wabash event.

Expected Damage to Memphis, TN Utility Systems			
Event	*Total Households*	*Without Water*	*Without Electricity*
6.5 New Madrid	253,670	0	88,751
7.5 New Madrid	253,670	12,810	149,720

Expected Damage to Little Rock, AR Utility Systems			
Event	*Total Households*	*Without Water*	*Without Electricity*
6.5 New Madrid	61,701	0	958
7.5 New Madrid	61,701	125	15,184

Expected Damage to Poplar Bluff, MO Utility Systems			
Event	*Total Households*	*Without Water*	*Without Electricity*
6.5 New Madrid	6,594	0	2,513
7.5 New Madrid	6.594	634	5,812

Expected Damage to Carbondale, IL Utility Systems			
Event	*Total Households*	*Without Water*	*Without Electricity*
6.5 New Madrid	12,469	0	637
7.5 New Madrid	12,469	291	4,889
7.0 Wabash	12,469	22	5995

Expected Damage to Evansville, IN Utility Systems			
Event	*Total Households*	*Without Water*	*Without Electricity*
6.5 New Madrid	33,938	0	594
7.5 New Madrid	33,938	0	7,887
7.0 Wabash	33,938	10,478	31,567

Expected Damage to Paducah, KY Utility Systems			
Event	*Total Households*	*Without Water*	*Without Electricity*
6.5 New Madrid	17,564	0	2,104
7.5 New Madrid	17,564	861	9,663
7.0 Wabash	17,564	12	7,392

Critical Facilities

The following tables show functionality of critical facilities. Critical Facilities are hospitals, fire stations, police stations and schools. These tables show event type, number of facilities, and number of facilities that have a functionality of greater than 50% at day 1. For a complete breakdown of facility type and functionality, see the Global Summary Report for each city.

Expected Damage to Memphis, TN Essential Facilities		
Event	*Number of Facilities*	*Functionality > 50% at Day 1*
6.5 New Madrid	164	164
7.5 New Madrid	164	0**

Expected Damage to Little Rock, AR Essential Facilities		
Event	*Number of Facilities*	*Functionality > 50% at Day 1*
6.5 New Madrid	163	163
7.5 New Madrid	163	163

Expected Damage to Poplar Bluff, MO Essential Facilities		
Event	*Number of Facilities*	*Functionality > 50% at Day 1*
6.5 New Madrid	36	36
7.5 New Madrid	36	0**

Expected Damage to Carbondale, IL Essential Facilities

Event	*Number of Facilities*	*Functionality > 50% at Day 1*
6.5 New Madrid	34	34
7.5 New Madrid	34	29
7.0 Wabash	34	5

Expected Damage to Evansville, IN Essential Facilities		
Event	*Number of Facilities*	*Functionality > 50% at Day 1*
6.5 New Madrid	85	85
7.5 New Madrid	85	85
7.0 Wabash	85	0**

Expected Damage to Paducah, KY Essential Facilities		
Event	*Number of Facilities*	*Functionality > 50% at Day 1*
6.5 New Madrid	41	41
7.5 New Madrid	41	0**
7.0 Wabash	41	41

** This "0" does not mean that HAZUS estimates that zero essential facilities will be available after the event. It means that HAZUS estimates that in the two cities, for the different events, that none of the essential facilities will have at least 50% functionality.

Shelter Requirements

HAZUS estimates the number of households that will be displaced following an earthquake. Below is a table showing the event type, city, and number of households displaced for each event/city. For a detailed view of shelter requirements, see the Global Summary Report for each city.

Expected Displaced Households			
Event	*Memphis, TN*	*Little Rock, AR*	*Poplar Bluff, MO*
6.5 New Madrid	228	0	10
7.5 New Madrid	2,608	204	250

Expected Displaced Households			
Event	*Carbondale, IL*	*Evansville, IN*	*Paducah, KY*
6.5 New Madrid	0	0	0
7.5 New Madrid	59	92	158
7.0 Wabash	59	2,989	41

Estimated Restoration and Replacement Costs

The following table shows the economic loss for the cities in the study and events specified. The amounts are in millions of dollars (M). For detailed information regarding economic losses, see the Global Summary Reports for each city.

Estimated Economic Losses			
Event	*Memphis, TN*	*Little Rock, AR*	*Poplar Bluff, MO*
6.5 New Madrid	$453 M	$13 M	$17 M
7.5 New Madrid	$2,197 M	$315 M	$139 M

Estimated Economic Losses			
Event	*Carbondale, IL*	*Evansville, IN*	*Paducah, KY*
6.5 New Madrid	$7 M	$7 M	$17 M
7.5 New Madrid	$112 M	$109 M	$175 M
7.0 Wabash	$76 M	$1, 648 M	$91 M