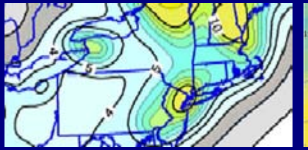
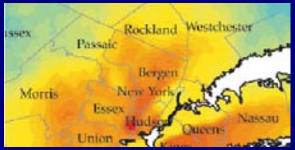
EARTHQUAKE RISKS AND MITIGATION IN THE NEW YORK | NEW JERSEY | CONNECTICUT REGION





# NYCEM

## THE NEW YORK CITY AREA CONSORTIUM FOR EARTHQUAKE LOSS MITIGATION

1999 - 2003

Summary report by

Michael Tantala
Guy Nordenson
George Deodatis
Klaus Jacob
Bruce Swiren
Michael Augustyniak
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Report Number MCEER-03-SP02

EARTHQUAKE RISKS AND MITIGATION IN THE NEW YORK | NEW JERSEY | CONNECTICUT REGION

# NYCEM

## THE NEW YORK CITY AREA CONSORTIUM FOR EARTHQUAKE LOSS MITIGATION

1999 - 2003

# ABOUT THIS STUDY

When we began this study in 1999, the date **9/11** was just another day on the calendar. It isn't any more. The destruction caused on that infamous day in 2001 has affected the nation profoundly. It has even affected the way studies such as ours perceive, assess, and mitigate risk. The terrorist attacks on the World Trade Center gave us a new benchmark for comparison: Would an earthquake in the New York City metro area incur comparable injuries, casualties, and financial losses?

The answer to this question is disconcerting. Even a moderate event (Magnitude 6) could result in an estimated 1100-1200 deaths, as well as igniting up to 900 fires simultaneously in the NY-NJ-CT region. Considering the large population (18.5 million) and the region's building inventory (predominately unreinforced masonry), it is clear that even a moderate earthquake would have critical consequences on public safety and the economy of this area.

## Who is NYCEM?

To create public awareness of seismic risk, the New York City Area Consortium for Earthquake Loss Mitigation (NYCEM) was formed in 1998. The group consists of interested organizations and major public and private stakeholders from federal and state emergency management, public service, engineering, architecture, financial and insurance companies, and academia.

## Why This Study?

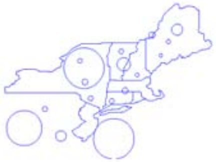
Our specific objectives for this study were to:

- Develop and implement a risk and loss estimation for the metropolitan NY-NJ-CT region using *HAZUS*, which is FEMA's methodology for performing loss estimations
- Assemble soil information for the entire Tri-State region to quantify details of the seismic hazard
- Compile a complete building inventory for Manhattan to estimate local impact, and a less detailed building inventory for the surrounding metropolitan areas to realistically quantify regional risk
- Identify and model a variety of earthquake scenarios and their probable consequences
- Assess the performance of individual, essential facilities relative to the probable demands placed on them
- Present results and recommendations for developing and implementing cost-effective risk management plans to reduce potential damage and losses.

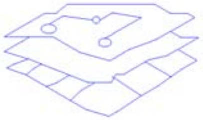
This report summarizes our findings. We believe the results outlined herein will help strengthen the already robust disaster management program in the NYC metro area.

*The New York City Area Consortium for Earthquake Loss Mitigation, www.nycem.org*

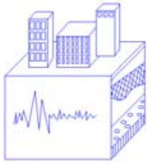
## OUR PROCESS AT A GLANCE



To forecast the consequences of earthquakes, it is important to assess risk by understanding what historically has happened in the region in terms of earthquake location, frequency, magnitude, and intensity of ground shaking.



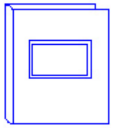
Geographic Information Systems (GIS) are used to relate information spatially. This framework is ideal for performing geographic calculations to ask “what if” situations for making informed decisions.



*Hazards US (HAZUS)* is a standardized methodology for performing loss estimations, using GIS to model the built environment against the backdrop of possible natural disasters. *HAZUS* was developed by FEMA in partnership with the National Institute of Building Sciences.

Once the earthquake hazard is studied, it is also important to know what is vulnerable – this includes people, buildings, contents, utilities, and potential business.

With a detailed inventory of information on geology, population, and building inventory, the *HAZUS* methodology may then be used to estimate the scale and extent of damage and disruption that may result from potential earthquakes.



Using informed estimates, it is possible to mitigate the risks and reduce potential losses from earthquakes by creating awareness, retrofitting existing buildings and infrastructure systems, better regulating future construction, better preparing response before an earthquake, and speeding response after one. Some implementation strategies have already been initiated and are discussed in this report.

## TABLE OF CONTENTS

RESULTS

APPLICATIONS

# EXECUTIVE SUMMARY

**While natural disasters cannot be avoided, we believe there are ways to improve safety, minimize loss and injury, and increase public awareness.**

While natural disasters cannot be avoided, there are ways to *improve safety, minimize loss* and *injury,* and *increase public awareness* of the risks involved. One of the most effective ways to lessen the impact of natural disasters on people and property is through risk assessment and mitigation – the topic of this study.

Conducted over a four-year period (1999-2003), the study is a thorough risk and loss assessment of potential earthquakes in the NY-NJ-CT region. This study documents the *scale and extent of damage and disruption* that may result if earthquakes of various magnitudes occurred in this area. In short, it addresses the first step in risk reduction: to identify potential problems. It focuses on the vulnerability of the building stock; future studies will deal with the inventory, fragilities, and losses from lifeline infrastructure systems, such as transportation, communication, water, liquid waste, and energy.

## An Earthquake in New York City?

The likelihood of an earthquake in New York City metropolitan area has been assessed as "moderate" by the U.S. Geological Survey. As recent as 2001 and 2002, two earthquakes of Magnitude 2.4 and 2.6, respectively, had epicenters around Central Park. Earthquakes of Magnitude 5.2 have a 20% to 40% probability of occurrence in 50 years in the study area. Based on seismic records, thousands of earthquakes with magnitudes larger than 2.0 have occurred in New York State over the past few centuries. Catastrophic events with Magnitudes 6 and larger are possibilities.

In order to be prepared for such natural disasters, we must be able to estimate and predict the risk associated with these potential losses. The economic impact of a damaging earthquake in New York City alone would be in the billions of dollars due to direct structural damage, not to mention the additional impacts on the infrastructure, building contents, business continuity, fire suppression, and human safety.

Thus, we believe this report is critical to emergency management officials, facilities managers, building architects, engineers, utility companies, insurance companies, business owners, and policymakers at all levels – local, state, and federal.

## Predicting the Consequences

How do you forecast the consequences of an earthquake? To predict what might happen in several "what-if" scenarios, we used Geographic Information Systems (GIS) and a model of the Tri-State area, including detailed data on the buildings and soil of the region. This information, supplemented with additional data about regional geology and history of earthquakes in the region (location, frequency, and magnitude), enabled us to identify the areas, structures, and systems at highest risk.

After identifying possible scenarios, we used federally sponsored software, *Hazards US (HAZUS)*, to estimate probable consequences and potential losses. Developed by the Federal Emergency Management Agency (FEMA) in partnership with the National Institute of Building Sciences (NIBS), *HAZUS* is a standardized, nationally applicable tool for performing loss estimations. Using *HAZUS* formats, we were able to establish the building inventory information for Manhattan at the level of individual buildings, a unique accomplishment for *HAZUS* applications.

***New York City would represent over half of the losses of the Tri-State region because of its dense built environment.***

## Minimizing Losses

Most losses caused by an earthquake are directly or indirectly the result of ground shaking and building damage or collapse. Even a moderate earthquake would severely impact the economy of the region. Our research indicates that the building inventory of the Tri-State region represents a total replacement value of $1 trillion, excluding contents and lifeline infrastructure systems. In a 2500-year event, which is the "maximum considered earthquake" used in designing new buildings, the combined loss of buildings and building-related income could be nearly $85 billion, comparable to the losses sustained on 9/11, albeit distributed over a larger area.

Using informed estimates, it is possible to mitigate the risks and reduce losses. Some key implementation strategies have already been initiated:

- Retrofitting vulnerable buildings and existing infrastructure
- Better regulating future construction by promoting seismic provisions in building codes and implementing them
- Adding earthquake scenarios to emergency response plans before and after an earthquake
- Increasing public awareness of the potential hazards.

## Creating Awareness

To increase public awareness of seismic risk in the area, the members of the Consortium will continue to gather data and information about area building stock, supporting infrastructures, and socio-economic systems. Other outreach efforts have included using building inventory data to assist in assessing damage from the 9/11 World Trade Center attacks, a Discovery Channel program on "Earthquakes in New York?" and numerous conferences, and news articles. We anticipate that the activities of the Consortium will stimulate broader community interest in joining this important effort.

## Looking Ahead

With a solid foundation of accurate regional data, the modeling approach can be extended to other disasters, such as hurricanes, snowstorms and floods. In fact, this research and its resources may be extended by implementing a "multi-hazards" approach to mitigation as part of a comprehensive disaster management program.

Emergency response and relief agencies may use this study to project the demand on essential facilities (hospitals, police, fire stations), as well as the financial and material resources required to assist victims. By looking ahead, not only will we be able to identify areas, structures, and systems at highest risk and improve our understanding of the problem, but also our understanding of the *number of lives* and *value at risk.*

Experience has shown that it is cost effective to invest a little now to save a lot later.

## KEY FINDINGS

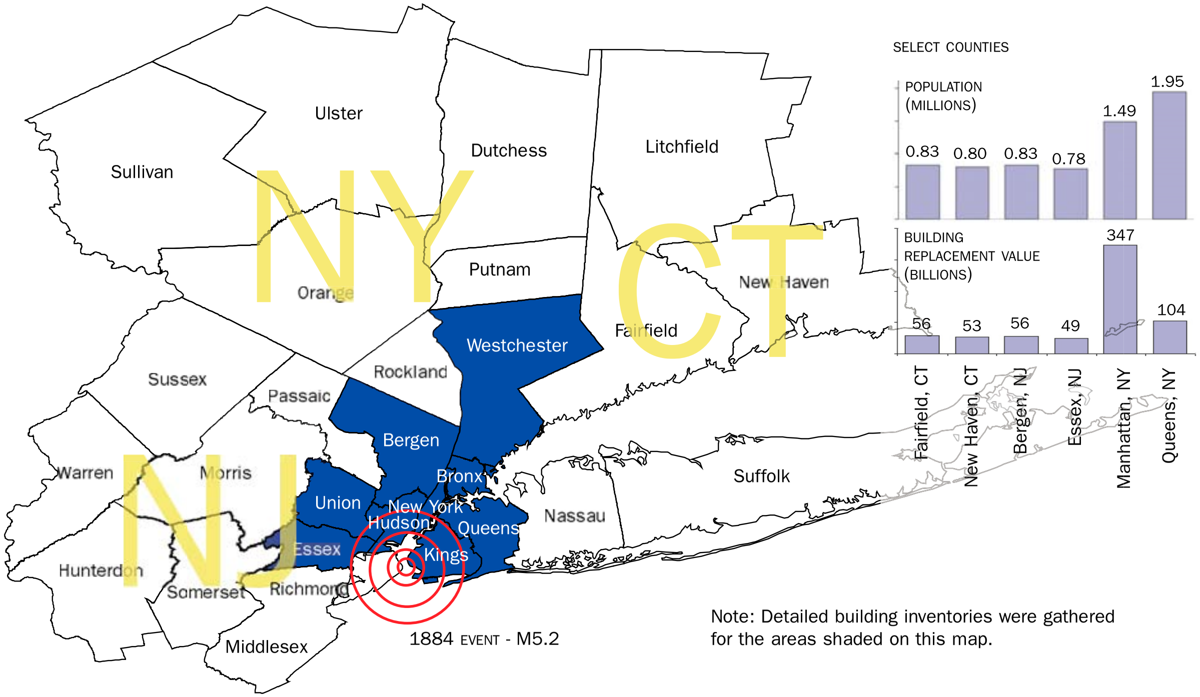
Although the NY-NJ-CT metro region has infrequent damaging earthquakes, it is generally considered *low hazard/high risk* because of its dense population, vulnerable infrastructure, and substantial economic value. Key findings on population and buildings at risk are summarized below.

### Population at Risk

The bar graphs on this page provide population information about six "select counties" in this study: Fairfield, CT, New Haven, CT; Bergen, NJ; Essex, NJ; New York, NY; and Queens, NY. These six counties, two from each state in the region of study, were selected because they have large populations and high replacement values.

The first bar graph shows that the counties with the largest populations – Queens County and New York County, respectively – contain nearly 3.5 million people, who would be at greater risk in the event of a moderate M5 earthquake, with an epicenter at the 1884 historic site. However, because the affected population is dispersed throughout the region, a moderate event would incur about one-third as many injuries and casualties as the 9/11 attacks on the high-occupation twin towers.

The map to the right illustrates the entire region of study (about 12,000 square miles) with a population of 18.5 million. The shaded areas represent the counties in which a more detailed building-by-building inventory was performed.



Note: Detailed building inventories were gathered for the areas shaded on this map.

### Buildings at Risk

The second bar graph shows the replacement value of the buildings in the six selected counties. The building inventory of the Tri-State region represents a combined 13 billion square feet and has a total replacement value of $1 trillion, excluding building contents and the value of all "non-building" infrastructure systems (i.e., transportation, water, power, sewer, etc.). There are 3.5 million buildings in this region, and 95% of them are residential.

The typical building in Manhattan is six to seven stories high, built at the turn of the century, made of either unreinforced masonry or steel, and used primarily as a multi-family dwelling or for commercial purposes. The replacement cost for buildings in Queens and Manhattan alone would total over $450 billion.

***The building inventory of the Tri-State region represents a total replacement value of $1 trillion, excluding building contents and "non-building" infrastructure systems.***

### Scenarios Studied

The table on the next page tabulates the damage and disruption that could happen in each of the scenarios studied:

- *M5, M6, M7 (fixed location scenarios)* are the different magnitude earthquakes located at a historic epicenter; namely, the M5.2 quake in NYC in 1884.

- *100-, 500-, 2500-year (probabilistic scenarios)* are the maximum expected losses over a given "return period," based on what has historically happened at that site. The 2500-year event is the so-called "maximum considered earthquake" and is of particular interest because it is the basis for the design of new buildings.

- *9/11/2001 World Trade Center* scenario, supplied for comparison, is the actual loss incurred as a result of the terrorist attacks.

## Even a moderate earthquake would have significant impact on the lives and economy of the Tri-State region.

### What Could Happen?

The table on this page states the damage and disruption that would happen in NY-NJ-CT in each of the scenarios studied. Estimates in the table do not include lifeline losses, which could easily increase these amounts by 30%. Some key findings are highlighted here:

- *Building and Income.* The two figures for building damage and income losses have been added together to derive the total dollar amount shown in color. Even in a moderate M5 quake, building and income losses would total $4.8 billion. In a 2500-year event, the total estimated losses ($84.8 billion) would be comparable to those of 9/11 ($98 billion). The greatest loss is incurred from a Magnitude 7.0 earthquake at the 1884 historic site with $198.6 billion, which is about 20% of the total building-replacement value for the entire Tri-State region. Because of its dense built environment, New York City represents over half of the losses of the Tri-State region for each scenario.

- *Hospitalization.* Hospital functionality would most likely be adequate for most scenarios, except for a M7 event, in which the estimated 13,171 injured (more than double 9/11), would require 26% more than the available number of beds.

- *Shelter Required.* In all scenarios, low-income housing, which is often concentrated in older buildings, may be the most severely affected, leading to homelessness and dislocation. Although only 300 people required shelter after 9/11, in a moderate M6 quake, the number could be close to 197,705. In a 2500-year event, over 84,626 people would require short-term shelter in schools.

- *Fires.* Losses resulting from fire after an earthquake can sometimes surpass the total losses from collapse of buildings and disruption of lifelines. Although the number and location of fire stations in Manhattan seem adequate for all scenarios, for larger events (>M6 or 2500-year), as many as 900 fires could break out simultaneously in the Tri-State study region, demanding more than the required gallons-per-minute (GPM) to fight them.

- *Buildings Damaged.* In a moderate M6 quake, an estimated 2,600 buildings would have complete damage, which is 130 times more buildings than were damaged on 9/11. In a 2500-year event, about 2,200 buildings would be damaged. Due to softer soils and predominantly unreinforced masonry buildings, the most vulnerable areas in Manhattan would be Chinatown and the Upper East Side.

- *Debris.* Debris generated in an earthquake is directly related to the damage estimates. Debris for a moderate M5 earthquake (1.6 million tons) would be comparable to that of the 9/11 tragedy (1.6 million tons). In Manhattan, the debris from a M5 quake would require nearly 10,000 times the daily trash hauling capacity. In a 2500-year event, the amount of debris (34.0 million tons) would be more than 21 times the debris cleared after 9/11 (1.6 million tons).

### How Many Lives Could be Lost?

Our results indicate that a moderate M6 quake at 2:00 in the afternoon, centered at the 1884 historic site, would cause 1,170 deaths. An event at 5:00 pm would result in slightly fewer fatalities, and at 2:00 am, the fewest. Predictably, the greatest concentration of deaths would be in and around the densely populated New York City metro area. In larger events, where there would be more collapses and partial collapses, there would also be proportionately more fatalities with additional threats from fire, which is not included in these estimates.

Considering the area's historic seismicity, population density, and vulnerability of the region's built environment, it is clear that even a moderate earthquake would have significant impact on the lives and economy of the Tri-State region.

**Essential Results of This Study for the Tri-State Region, and for Scenarios Listed in First Column**

| SCENARIO | BUILDING | INCOME | TOTAL | HOSPITALIZATION | SHELTER REQUIRED | FIRES | BUILDINGS: COMPLETE DAMAGE | DEBRIS |
|---|---|---|---|---|---|---|---|---|
| **M5** | $4.4 b | $0.4 b | **$4.8 b** | 24 | 2,800 | 500 | 45 | 1.6 m tons |
| **M6** | $28.5 b | $10.8 b | **$39.3 b** | 2,296 | 197,705 | 900 | 2,600 | 31.9 m tons |
| **M7** | $139.8 b | $57.1 b | **$196.8 b** | 13,171 | 766,746 | 1,200 | 12,800 | 132.1 m tons |
| **100-year** | $0.1 b | $0.1 b | **$0.2 b** | 0 | 0 | 0 | 0 | 0.2 m tons |
| **500-year** | $6.1 b | $2.0 b | **$8.1 b** | 28 | 575 | 50 | 100 | 3.1 m tons |
| **2500-year** | $64.3 b | $20.4 b | **$84.8 b** | 1,430 | 84,626 | 900 | 2,200 | 34.0 m tons |
| **Annualized Losses** | $0.1 b | $0.1 b | **$0.2 b** | 0 | 0 | 0 | 0 | 0 |
| **9\|11\|2001** | $13.0 b[1] | $52-64 b[2] | **$98.0 b** | 6,000 | 300 | 10 | 20 | 1.6 m tons |

Different magnitudes at a NYC 1884 historic location.

Different expected losses over a given period of time.

Comparison to the 9|11 terrorist attacks.

[1] New York State Insurance Department

[2] Thompson 2002

# WHY IS THIS STUDY SIGNIFICANT?

## *This is one of the most significant and extensive loss estimation studies to date.*

Earthquakes are both uncontrollable and unpredictable. However, years of research have yielded a knowledge base for predicting *the areas* that might be most vulnerable, *the extent* of damage and disruption that could result, and *the ways* to mitigate risk and save lives. And, this knowledge base continues to grow. A study such as this one, assessing seismic risk and consequences for the NY-NJ-CT region, is important for several reasons:

### Identifies Specific Areas at Risk

This work pinpoints areas in the Tri-State region that would be most vulnerable in different scenarios: What types of buildings in this region are most likely to collapse? Which would have the least risk of collapsing? What areas would be expected to have the most damaged buildings? Answering these questions with precision requires assembling detailed data on all of the buildings and soil types in the region, modeling a variety of earthquake scenarios, and predicting their probable consequences. The resulting study is one of the most significant and extensive loss estimation studies to date. The substantial knowledge base it has yielded can help mitigate loss and save lives.

### Estimates Potential Losses

This study is important because it provides comprehensive, quantitative estimates of potential losses (i.e., the value at risk) for a variety of earthquake scenarios: How many injuries and casualties might there be in earthquakes of different magnitudes? How much would it cost to repair and replace damaged buildings? How much revenue would be lost? How many people would be displaced from their residences?

### Assesses Critical Facilities

Additionally, this work is important because it assesses the performance of individual essential facilities (police, hospital, and school shelter) and the probable demands placed on them: How many people would require hospitalization or temporary shelter in schools? Would the affected area have sufficient capacity for this many people? Are there enough police and fire stations? Note that lifeline infrastructure losses (subways, bridges, power, etc.) are not included. Lifelines require further data collection and loss and impact assessments.

### Predicts Induced Hazards

In earthquakes, induced hazards may include fire, homelessness, inoperable water systems, and other disaster-related problems. This study is important because it predicts the extent of induced, secondary hazards should a seismic event occur in the NYC metro area. For example: How many fires are likely to ignite and where? How many people would likely be exposed to those fires? Would the water capacity be sufficient to fight the fires? Would there be enough trash-hauling capacity for all the debris?

In short, it is our hope that this study will help policy makers, practitioners, and researchers understand the value at risk in this region and form strategies to reduce seismic impact.

# HOW SHOULD THIS STUDY BE USED?

> ***Regional, state, and federal officials may use estimates of injuries and casualties to project demand on medical resources.***

This study has made a significant contribution toward improving our understanding of earthquakes in this region by forecasting potential losses. The primary estimates in this study may be used in several ways *before* and *after* an earthquake:

### To Mitigate Possible Losses Before an Earthquake

Reducing earthquake loss begins before the earthquake. Loss estimates provide public and private sector agencies with a basis for planning, zoning, building codes, development regulations, strengthening of vulnerable essential facilities, and policy that reduce the risk posed by ground shaking. Loss estimates can also be used to evaluate the cost effectiveness of alternative approaches to strengthening potentially hazardous structures.

### To Prepare Response Before an Earthquake

Understanding the scope and complexity of earthquake damage is essential to effective preparedness. This study forecasts damage to buildings, number of casualties, and disruption of key facilities. These estimates can be the basis for developing emergency-response plans needed to cope with an earthquake-related disaster.

### To Speed Response and Relief After an Earthquake

Typically, the first 24 hours after an earthquake are the most crucial for saving lives and reducing injuries. Expediting relief to victims may help to reduce loss of life and complications from injuries. Response and relief agencies can use this study to predict the likelihood of casualties, damages, economic loss, and the number of homeless, as well as to estimate the financial and material resources necessary to assist victims. Regional, state, and federal officials may use estimates of injuries and casualties to project demand on medical resources.

### To Improve Disaster Resiliency of the Area

With a solid foundation of accurate regional data, the modeling approach can be extended to other disasters (hurricane, flood, snow storm, landslide, tornado, explosion, terrorism) in an effort to improve the disaster resiliency of the metropolitan area.

### To Promote Public Awareness of the Potential Problems

Typically, localities with infrequent earthquakes place a low priority on seismic code development, adoption, and enforcement. This study describes potential consequences and their significance in the community and region in an effort to promote public awareness of the potential problems. The information could also be used to support the adoption and enforcement of seismic building codes in regions of the United States that experience infrequent, but damaging, earthquakes.

**More than 400 earthquakes with Magnitude greater than 2.0 are on record in New York State between 1730 and 1986, and many more have occurred unrecorded.**

Although earthquake losses in the United States are known to occur predominantly in California, many significant earthquakes in the Northeast have occurred, and more are projected largely in the areas that have been active in the last few centuries.

### Seismicity in New York State and Eastern North America

More than 400 earthquakes with Magnitude greater than 2.0 are on record in New York State between 1730 and 1986, but many more have occurred unrecorded. East of the Rocky Mountains, only South Carolina, Tennessee and Missouri were more seismically active during this period and, as such, New York State ranks third highest in earthquake activity level east of the Mississippi River.

The map on the next page identifies the most significant seismic events in New York State in the past few centuries. In chronological order, they are as follows:

| Date | Magnitude | Epicenter |
|---|---|---|
| 1737 | 5.2 | New York City |
| 1884 | 5.2 | New York City |
| 1929 | 5.2 | Attica, NY |
| 1944 | 5.8 | Cornwall-Massena, NY |
| 1983 | 5.1 | Goodnow, NY |
| 2002 | 5.1 | Ausable Forks, NY |

The map (next page) also shows the epicenters of thousands of other earthquakes of M3.0 intensity or higher that have occurred in and near the northeastern United States over the past few centuries; thousands more occur with Magnitudes below 3.0.

Among the largest historic earthquakes that occurred in Eastern North America (East of the Rocky Mountains) are the 1663 M7, Charlevoix, Quebec earthquake; three events in 1811/1812 with M7 or larger along the Mississippi River (in the New Madrid Seismic Zone near the Tennessee-Missouri boundary); and in 1886 about M7 near Charleston, South Carolina. Together these events prove that such large earthquakes are possible, albeit rare, in Eastern North America.

### Seismicity in the New York City Area

On December 18, 1737, chimneys reportedly fell when a Magnitude 5 to 5.5 earthquake rocked New York City. Another moderate M5.2 quake occurred in the New York City area on August 10, 1884. This 1884 event remains the best-documented earthquake for this region. It was a strong shock, centered off Rockaway Beach, about 17 miles southeast of New York City Hall, and was felt over 70,000 square miles – from Vermont to Maryland.

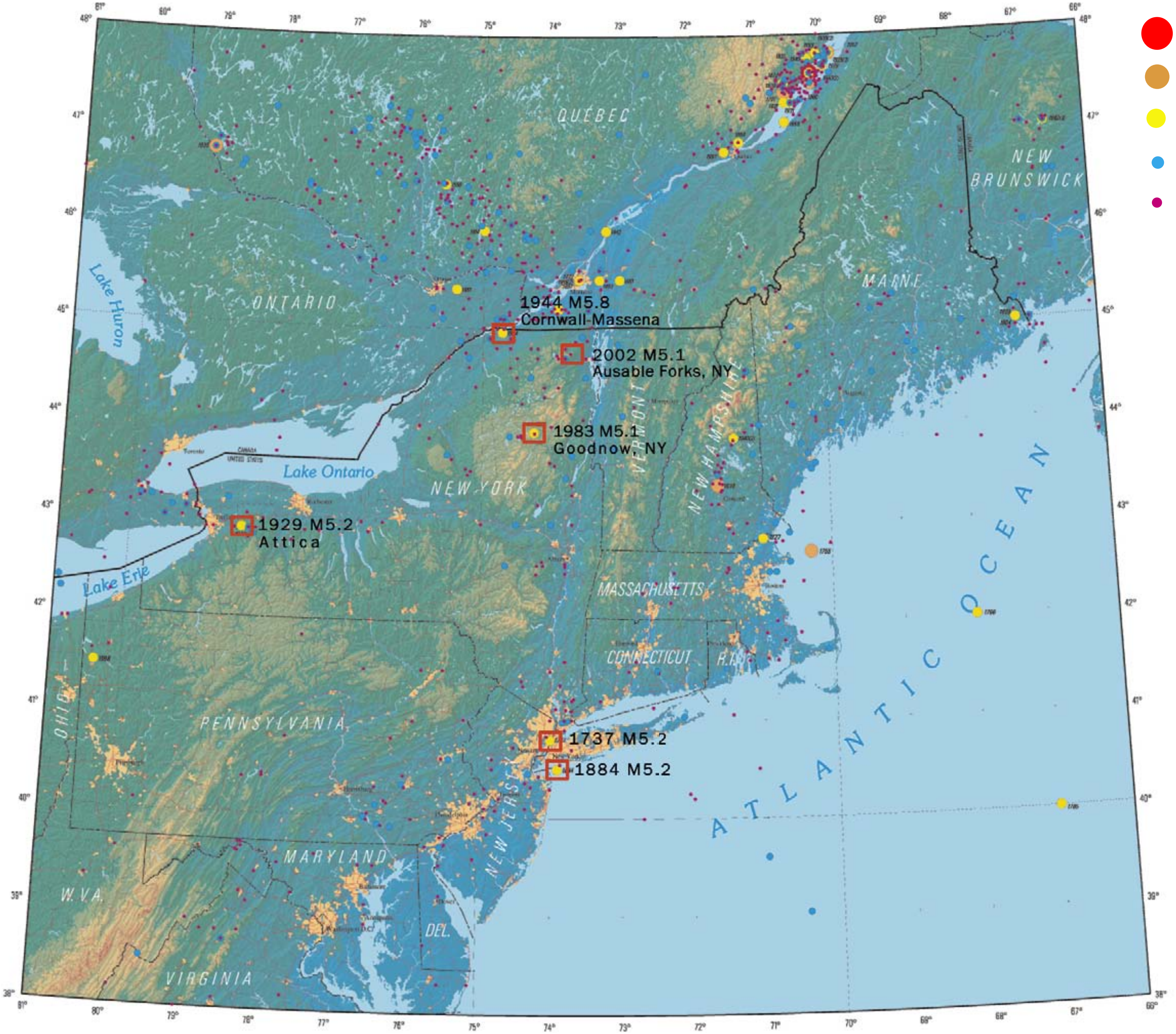
### Probability of Earthquakes in New York City

New York City's seismic risk is a growing concern. A study conducted in the mid-1980s (see Nordenson 1987, 2000), which characterized the seismicity of New York City as "moderate," had the following findings:

- In past centuries, earthquakes with Magnitude 5.0 have occurred about every 100 years in the New York City area. Modern New York City is ill prepared even for such moderate events.
- Regional seismicity indicates that future earthquakes of Magnitude 5.2 are likely to occur on average every 100-200 years, with a 20% to 40% probability of occurrence in any 50 - year period.
- Larger earthquakes with magnitudes up to 6.8, the probable upper bound, may occur less frequently.
- Even larger magnitudes at very low levels of probability cannot be excluded.

As you can see from the aerial map on the next page, smaller, more recent events with epicenters around Central Park occurred on January 17, 2001 (M2.4) and November 27, 2002 (M2.6). Although New York City is a region with *low seismic hazard* (infrequent damaging earthquakes), it actually has *high seismic risk* because of its tremendous assets, concentration of buildings, and the fragility of its structures, most of which haven't been seismically designed.

# EARTHQUAKES IN THE REGION (cont.)



EARTHQUAKE MAGNITUDE

| | |
|---|---|
| ● | 7.0 and greater |
| ● | 6.0 - 6.9 |
| ● | 5.0 - 5.9 |
| ● | 4.0 - 4.9 |
| ● | 3.0 - 3.9 |

Note: Thousands of earthquakes occur with Magnitudes below 3.0.

This map catalogs the epicenters of thousands of earthquakes with Magnitudes larger than 3 that have occurred over the past few centuries. More significant and recent events are labeled.

Source: USGS, modified by the NYCEM study team. U.S. Geological Survey Geologic Investigations Series I-2737, “Earthquakes In and Near the Northeastern United States”, 1638-1998 by Russell L. Wheeler, Nathan K. Trevor, Arthur C. Tarr, and Anthony J. Crone.

# EARTHQUAKES IN THE REGION (cont.)

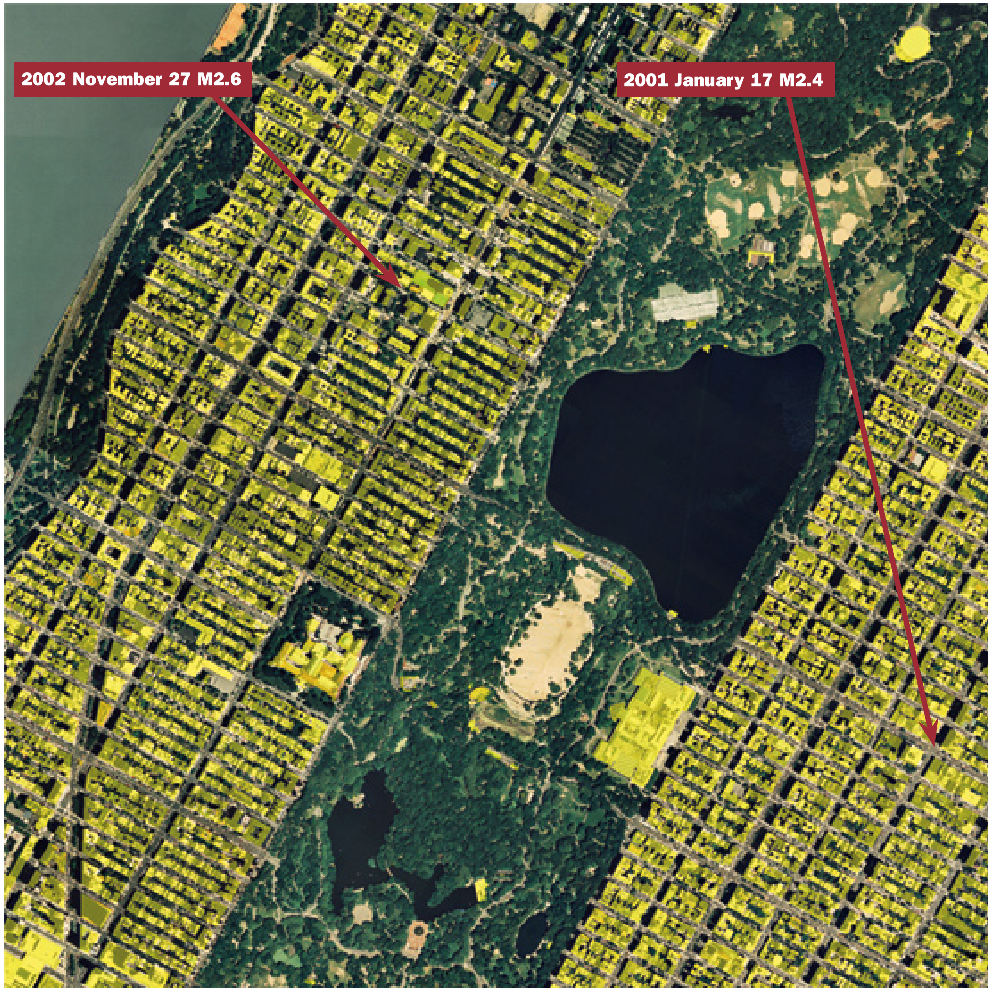
## Manhattan Building Codes

The study mentioned above also found that the seismicity of New York City is similar to that of the Boston area, where local seismic design provisions have been in effect for a few decades. The first seismic building code for New York City was passed only in 1995.

The consensus opinion is that retrofitting thousands of New York buildings to meet seismic standards is impractical and economically unrealistic. Therefore, it is even more important to identify areas of highest potential vulnerability to earthquake ground shaking so that mitigation, emergency response, and recovery approaches can be strengthened.

***Earthquakes with Magnitude 5 have occurred about every 100 years in the New York City area.***

This map shows midtown Manhattan and the epicenters of two recent earthquakes centered around Central Park.



Source of aerial imagery: New York City Department of Information Technology and Telecommunications (DoITT), NYC Basemap.

***In the event of a damaging earthquake in the NY-NJ-CT region, about 18.5 million lives in 7 million households would be at risk.***

## Population

In the event of a damaging earthquake in the NY-NJ-CT region, about 18.5 million people in 7 million households would be at risk. The number of human fatalities is the ultimate measure of severity in any disaster.

## Buildings and Real Estate

The large population lives and works in about 3.5 million buildings with a combined 13 billion square feet and a total replacement value of $1 trillion, excluding contents. About 95% of the buildings are residential. The region occupies nearly 12,000 square miles, has 28 counties, and contains about 5,000 census tracts.

## Infrastructure and Essential Facilities

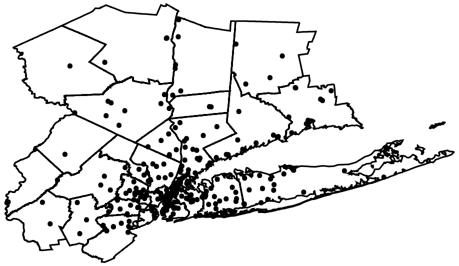
The region has a very valuable infrastructure that would be severely at risk in the event of a damaging earthquake. Replacing transportation and utility systems alone is estimated to cost $200 billion. Add to this the damage to essential facilities, and the value at risk increases significantly:

- 246 hospitals
- 123 emergency operation facilities
- 878 fire stations
- 1,348 dams (402 considered "high hazard")
- 744 police stations
- 53,095 hazardous material sites
- 2 nuclear power plants

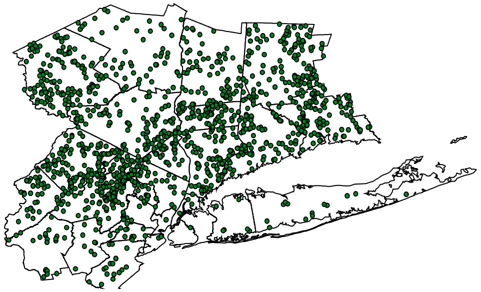
The maps on this page catalog some of the facilities with a high potential for loss in this region:

- Airport facilities
- Power distribution facilities
- Dams
- Schools
- Highways

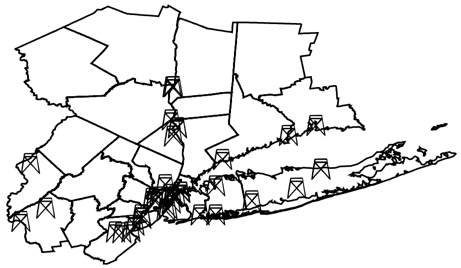
AIRPORT FACILITIES



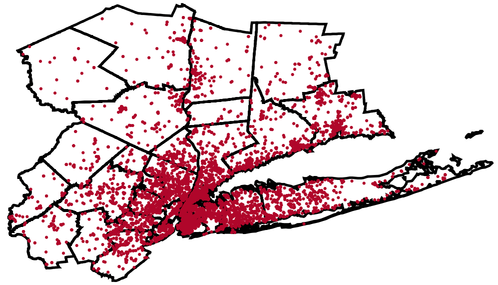
DAMS



POWER DISTRIBUTION FACILITIES



SCHOOLS

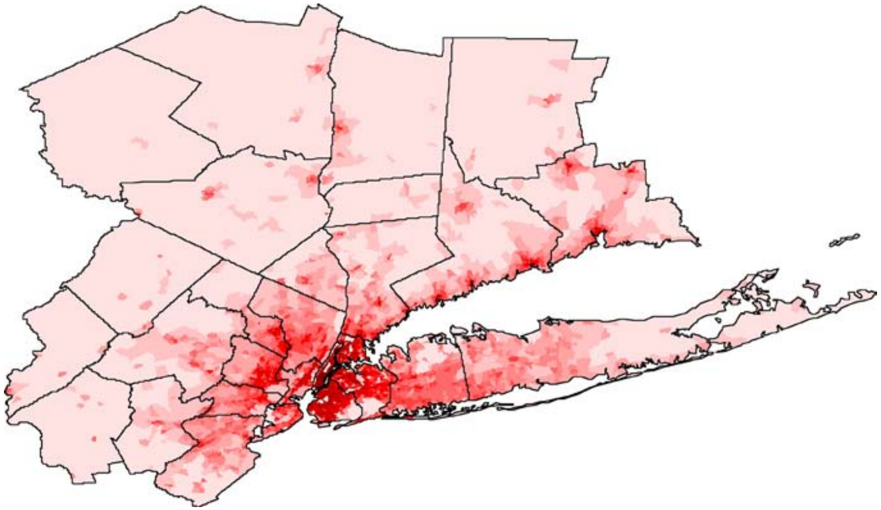


HIGHWAY INFRASTRUCTURES

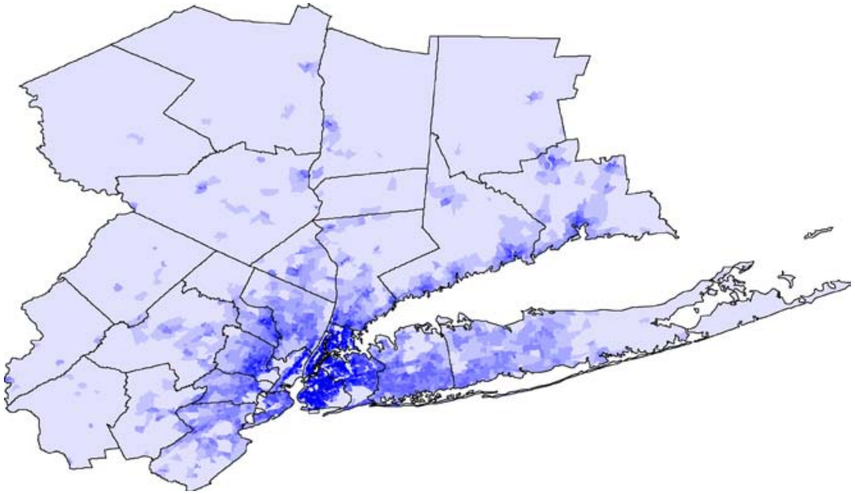
These maps catalog some of the infrastructure at risk as a result of potential earthquakes: airport facilities, power distribution facilities, dams, schools and highways.

# VALUE AT RISK (cont.)

DISTRIBUTION OF REPLACEMENT COST ($1 TRILLION TOTAL)



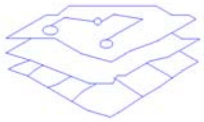
POPULATION DISTRIBUTION (18.5 MILLION TOTAL)



The distribution of the 1 trillion dollar replacement value also varies within the region and is shown above to the left. The distribution of population is shown above.

***The greatest damage and concentration of deaths would be in and around the densely populated New York City metro area.***

## *Geographic Information Systems helped to forecast how ground motions generated by scenario earthquakes would be distributed to different buildings within a region.*



### Mapping the Data

With a study of this size, we needed a system that could analyze large amounts of data. Our solution was Geographic Information Systems (GIS) technology. GIS is a computer system capable of capturing, storing, analyzing, and displaying large amounts of geographically referenced information. (See http://erg.usgs.gov/isb/pubs/gis_poster/).

To begin, we used GIS to develop geographically based databases and map them in relation to one another. We were able to highlight areas of interest and view, understand, question, interpret, and visualize the data in ways that weren't possible until mapped and related. With this system, we were able to identify and model a variety of hypothetical earthquake scenarios and their probable consequences.

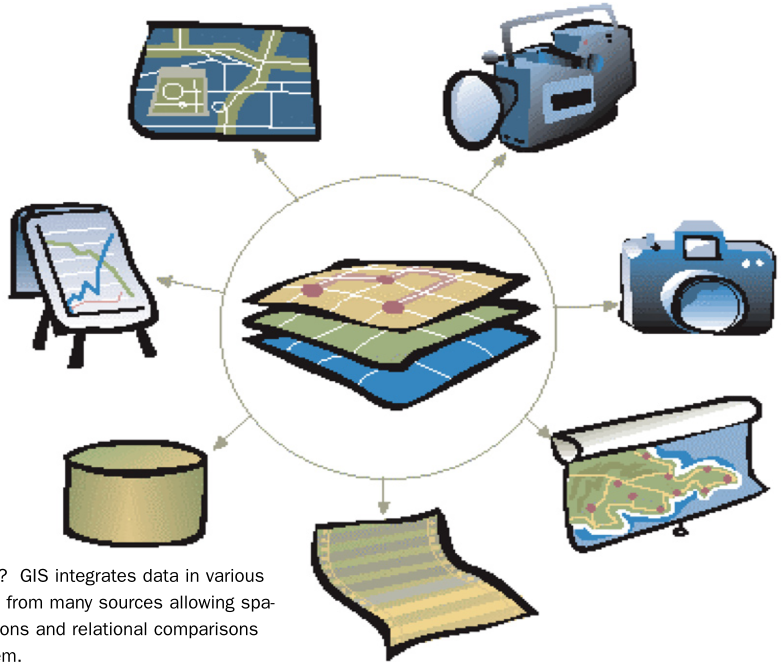
### Forecasting Locations

With GIS technology, we were able to relate different information in a spatial context and reach a conclusion about these relationships. For example, using data about soil and the age, size, and value of buildings, we were able to relate the intensity of ground motions to every building in the region and estimate *what losses* might result. Moreover, we were able to forecast how earthquake ground motions generated by likely scenario events would be distributed to different buildings within a region.

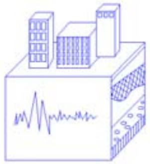
Additional information was linked to population information, distance to the nearest hospital, police station, fire station, and more. All in all, GIS tools and methods enhanced the efficiency and analytical power of traditional cartography.

### Using Risk Assessment Software

In partnership with the National Institute for Building Sciences, FEMA's Mitigation Division has developed a risk assessment software program, *Hazards US* (*HAZUS*), for analyzing potential losses from earthquakes, floods, and hurricane winds. The software uses the latest scientific and engineering knowledge, plus GIS technology, to produce estimates of hazard-related damage before or after a disaster occurs, including social impacts, physical damage, and economic loss (See http://www.fema.gov/hazus/). Using *HAZUS* risk assessment software, we were able to estimate the scale and extent of damage and disruption that may result from potential earthquakes in the NY-NJ-CT region.



What is GIS? GIS integrates data in various formats and from many sources allowing spatial calculations and relational comparisons between them.



**With HAZUS *risk assessment software, we were able to estimate the scale and extent of damage and disruption that may result from potential earthquakes in the NY-NJ-CT region.***

## Calculating Potential Losses

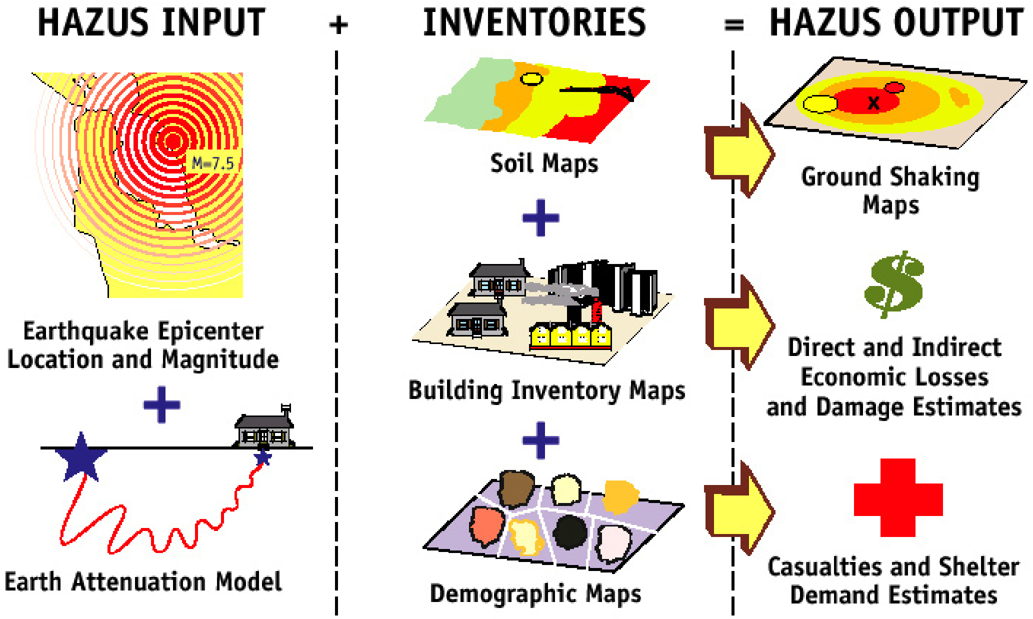
The figure on this page illustrates how *HAZUS* software calculates potential losses. Once the size and location (epicenter) of a hypothetical earthquake is selected, the software uses a series of mathematical formulas to calculate the intensity of ground shaking, the amount of damage, the disruption and economic losses caused by the earthquake, the number of casualties, and the number of people displaced by damaged structures. Moreover, by changing the size and location of hypothetical earthquakes, we were able to see the range of damage that may occur in the community.

To generate more accurate estimates, we incorporated region-specific "inventories," including soil maps, building inventory maps, and demographic maps. The "outputs" from these inventories are illustrated in the figure on this page:

- Information on soil conditions helped determine the estimated shaking intensity that a structure would experience; regions with softer soil tend to have a greater likelihood of damage.
- Building inventory maps (e.g., how buildings were constructed, how old, how tall, their value, etc.) were essential for calculating economic losses and estimating damages.
- Demographic information enabled *HAZUS* to determine casualties and shelter requirements for various earthquake scenarios.

## Why Do We Need to Estimate Earthquake Losses?

If we can predict which parts of the community would experience the most violent shaking, which buildings would sustain the greatest damage, and which areas would likely sustain the most casualties, then we can develop appropriate emergency response plans and engineer buildings and infrastructures to withstand earthquakes. Loss estimates can also help state and federal governments plan for assistance to jurisdictions and disaster victims.



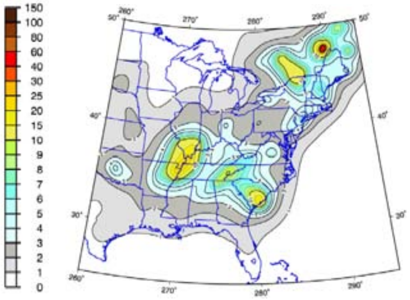
Using Geographic Information Systems (GIS) technology, the *HAZUS* methodology computes estimates of damage and loss that could result from an earthquake.

# ASSESSING EARTHQUAKE HAZARDS: TWO METHODS

DETERMINISTIC EVENTS SPECIFIED AT THE 1884 EPICENTER FOR M5, M6, M7

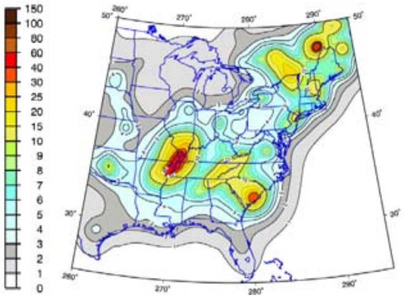
Ground Shaking (PGA) is attenuated from the epicenter (star) for the three magnitudes, and then related to soil and building information to estimate losses.

PROBABILISTIC SCENARIO 100-YR RETURN PERIOD [40% CHANCE IN 50 YEARS]



Ground Shaking (PGA) is determined based on all historic earthquakes and regional ground motion attenuation, and then related to soil and building information to estimate losses.

PROBABILISTIC SCENARIO 500-YR RETURN PERIOD [10% CHANCE IN 50 YEARS]



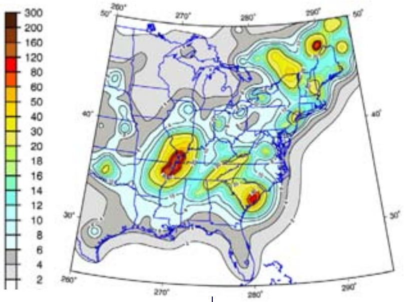
Our study used two earthquake-modeling methods to assess seismic hazards and risks, and to estimate losses:

‣ *Deterministic:* This method assumes the location and magnitude of specified scenario earthquakes and determines the effects from these particular events.

‣ *Probabilistic:* This method uses the information from all historic earthquakes, plus geologically inferred earthquake sources (faults, locations and magnitudes), and computes the probable ground shaking levels that may be experienced during, say, a 100-year, 500-year or 2,500-year recurrence period.

These two methods complement one another. Deterministic scenarios provide the "what if" answers for particular assumed earthquakes. As we change their magnitudes and locations, we can see how various areas are differentially affected by different events. However, for deterministic scenarios, we do not ask how likely each scenarios is. The deterministic scenarios are good for testing a region's emergency preparedness and how it would cope with disaster losses of various magnitudes.

PROBABILISTIC SCENARIO 2500-YR RETURN PERIOD [2% CHANCE IN 50 YEARS]



The probabilistic, 2500-yr-return-period ground motions are the basis for the design of new buildings. This is the so-called "Maximum Considered Earthquake." Code-designed new buildings may be damaged by this level of hazard, but they should not collapse or cause major loss of life. Results for this case will correlate with current design practice expectations for new buildings.

In contrast, the probabilistic assessment finds the long-term likelihood of shaking in each area and, therefore, tells how hazardous a given area is compared to others nearby. It tells how this shaking hazard increases when we consider even longer recurrence periods, namely the expected shaking for a 100-year, 500-year, or 2,500-year recurrence time. These probabilistic estimates serve best for urban planning, land-use, zoning, and seismic building code regulations, but they also help to determine risk-based earthquake insurance premiums.

## Deterministic Method

Since this method is based on predetermined scenario earthquakes, we chose the 1884 M5.2 historic earthquake, located off shore of Brooklyn, represented by the star on the first map to the left. However, instead of a single magnitude, we compared the effects of three magnitudes – M5, M6 and M7 – in the surrounding region. Using HAZUS, we were able to model the ground motions traveling from these three sources to each building (i.e., attenuation relationships). To estimate losses, we related the intensity of ground shaking (peak ground acceleration, PGA) to soil and building information. The softer the soil, the greater the ground motion, and the greater the chance of damage, loss, and casualties. This is why an accurate soil map is so important for making reliable loss estimates.

## Probabilistic Method

When you base your predictions on the probability of earthquake shaking during a preset time period, the scenarios are called probabilistic. In contrast to the deterministic method, probabilistic analyses allow for uncertainties in the earthquake magnitudes and locations, and of the levels of ground motions that can be expected. The three contour maps on this page, developed by the U.S. Geological Survey, show the expected intensity of ground shaking (PGA) in the eastern U.S. for the three average return periods (100, 500, and 2,500 years) chosen for our study. The three assessments correspond to probabilities of 40%, 10% and 2%, respectively, that in any 50 year-period the mapped ground motion values would be exceeded. We combined these regional shaking maps with detailed maps of local soil conditions to determine more accurate local ground shaking levels. Once the ground motion (PGA) is known for every building, the likelihood of damage may be determined, based on the type of building.

# ROCK AND SOIL TYPES IN THE REGION

***Soft soils are widespread in the region. They can amplify ground shaking to damaging levels even in a moderate earthquake.***

Knowing the geologic distribution of the rocks and soils in a region is critical for assessing earthquake losses. We used different data sources and procedures to map the modification of ground shaking by these local geological factors, employing a prescribed *HAZUS* format. The sources include:

### NEHRP Site Classification Scheme

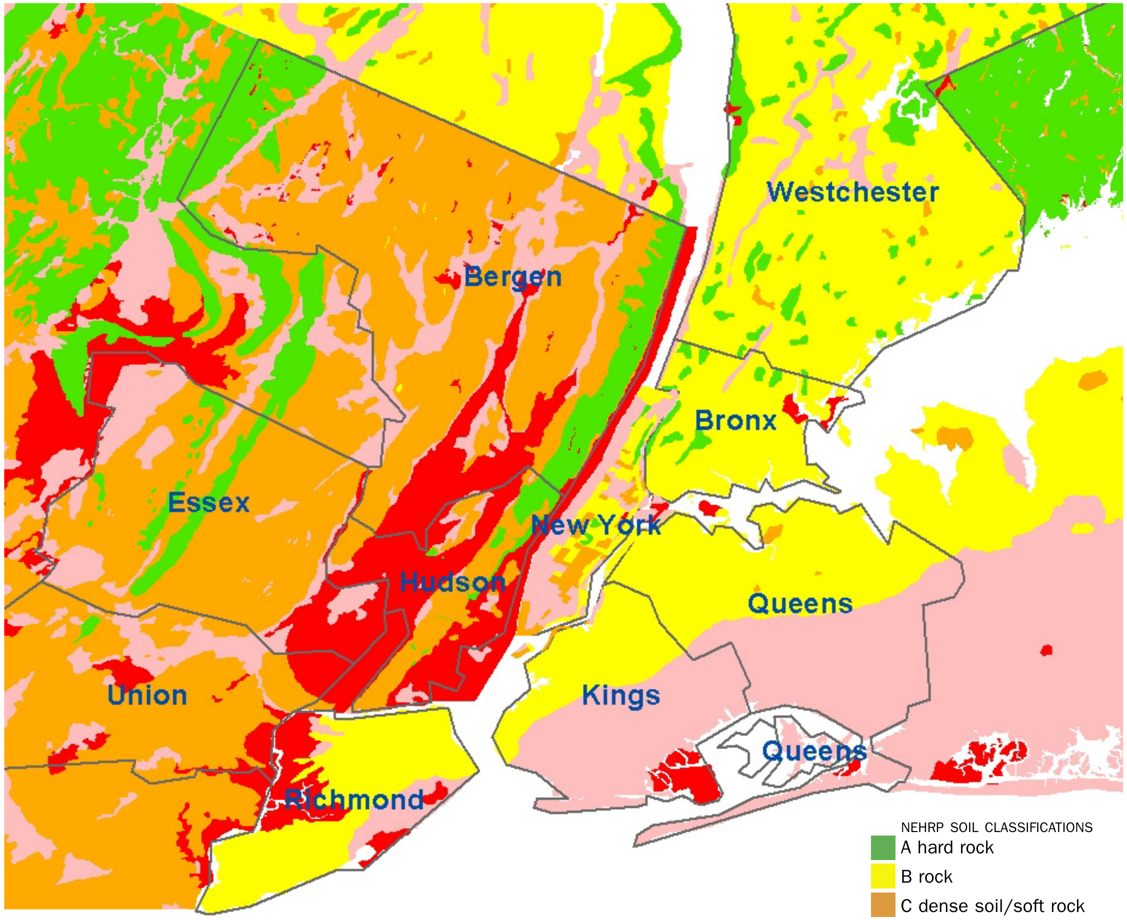
The 1997 National Earthquake Hazard Reduction Program (NEHRP) provides rules for classifying sites according to the stiffness of geological materials. The site classes range from A to E, where A represents the hardest rocks, and E the softest soils. These classifications are used in all figures on this and the next few pages. Soft soils amplify ground shaking and increase building damage and losses. *HAZUS* uses predetermined NEHRP ground shaking amplification factors for each of these soil classes.

### State Geological Maps

To classify sites according to the NEHRP site classes A through E, we obtained geotechnical data from a variety of different sources with varying quality and spatial resolution.

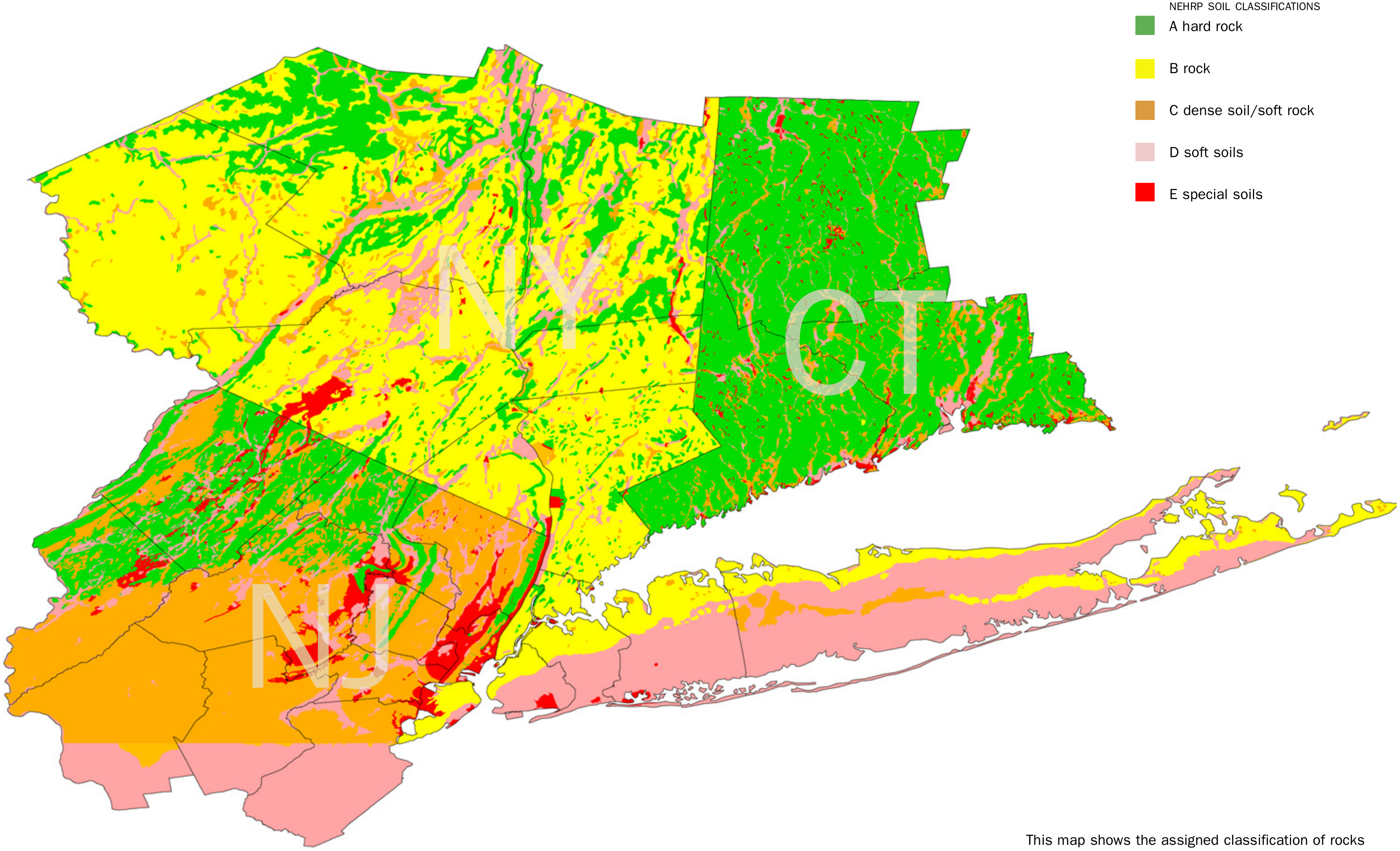
In the regions outside Manhattan (see map on this page) and in the surrounding Tri-State region of NY-NJ-CT (see next page), site classification is based on lower-resolution surface geology maps provided by the different state geological surveys. The three states mapped similar rock and soil units differently. We established rules by which we assigned geological units on the Site Maps to the NEHRP site classes A through E. This procedure resulted in only minor differences in site classes across state boundaries. There is, however, good agreement for the more critical, soft-soil classes that amplify the ground motions. Since soft soils are widespread in this region, they can amplify ground shaking to damaging levels even in a moderate earthquake.

For loss computations in *HAZUS*, the maps of site classes in the NY-NJ-CT region outside Manhattan (on this and the next page) were overlain with the outlines of census tracts. Census tracts are small areas within a county or city used for population and related statistics. We assigned a single site class to each census tract based on the site class that was found at the center of each tract. More complex schemes are possible but were not employed here.



This map shows the types of soils in the New York metropolitan region.  Higher resolution data was used for Manhattan.

# MAPPING SOIL TYPES IN THE REGION



This map shows the assigned classification of rocks and soils in the Tri-State region. This information is critical for estimating losses because softer soils tend to amplify ground motion and, therefore, increase chance of damage.

# SOIL TYPES IN MANHATTAN

Due to the high density of buildings in Manhattan, we used higher-resolution methods to determine rock and soil properties in greater detail. Most data came from geotechnical borings of pre-existing construction projects. Several different data sources and analytical procedures were used:

## Standard Penetration Tests and Soil Borings

The more recent data represent Standard Penetration Test (SPT) “blow counts.” The “blow count” is the number of blows (using a standard hammer weight) needed to achieve a penetration of 1 foot of soil. This SPT blow count gives an indication of the stiffness of the geological materials. The common method is to drill a borehole. Standard Penetration Tests can be conducted inside the borehole. Depending on the distribution of blow counts with depth in the boreholes, a single NEHRP site class (from A to E) is assigned to each borehole site.

## Depth-to-Bedrock Borings

Older data represent only depth-to-bedrock (DBR) borings, in which the stiffness of the overlying soil layers was not determined for each boring. The DBR borings constitute almost 90 percent of all data in Manhattan. We derived a standard profile of soil stiffness as a function of soil depth. Then the depth to bedrock boring directly translates into a site class from A (rock at very shallow depth or outcropping) to D (with very large depth to bedrock). This method does not allow assigning the softest soil class E. The black dots (see figure to the right) represent more than 3,000 boring sites gathered from the past 100 years of construction.

## Thiessen Polygon Maps

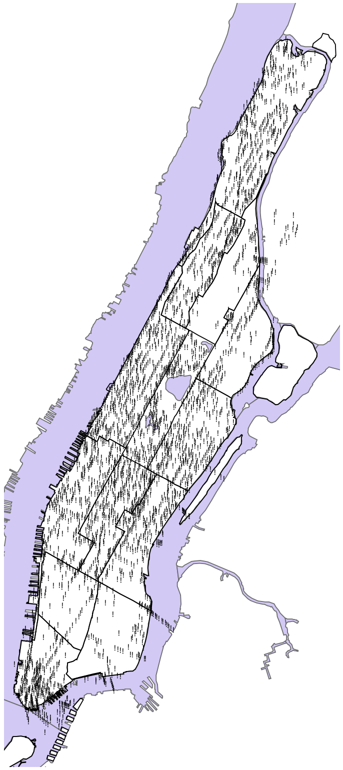
The second figure is derived from DBR point data and the “Thiessen Polygon” mapping tool. With this tool, we were able to contour the site class point data, optimized to the spatial distribution of the borings.  Each one of the polygons defines a region of a single site class and is controlled by the class of the central point within the polygon.

## Census Tract-Based Maps

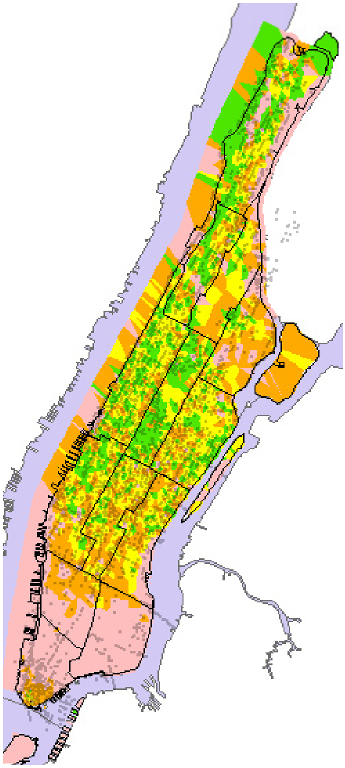
The third figure uses DBR and SPT point data, plus census tracts employed by *HAZUS,* assigning a predominant site class to each census tract, based on the borings it contains. Census-tract-based maps assign a single site class to a sizeable census tract, which often may contain rapidly varying site geology. Nevertheless, such maps are useful in improving the loss computations generated by *HAZUS*.

The results from both types of maps indicate that lower Manhattan and the Upper East Side are predominately soft soil (Class D).  Most of the remainder of Manhattan has relatively stiffer soils (Class B and C), which do not amplify ground shaking as much.

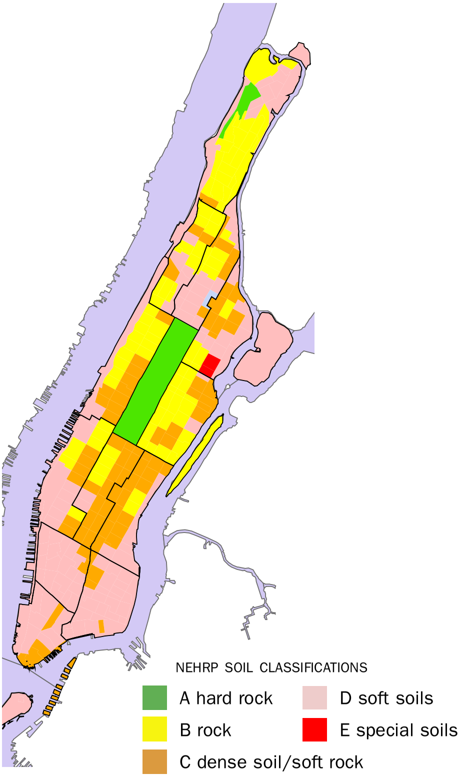
Boring data map for Manhattan which was used to create the next “Thiessen Polygon” map.



“Thiessen Polygon” map of site classes in Manhattan derived from depth-to-bedrock data only.

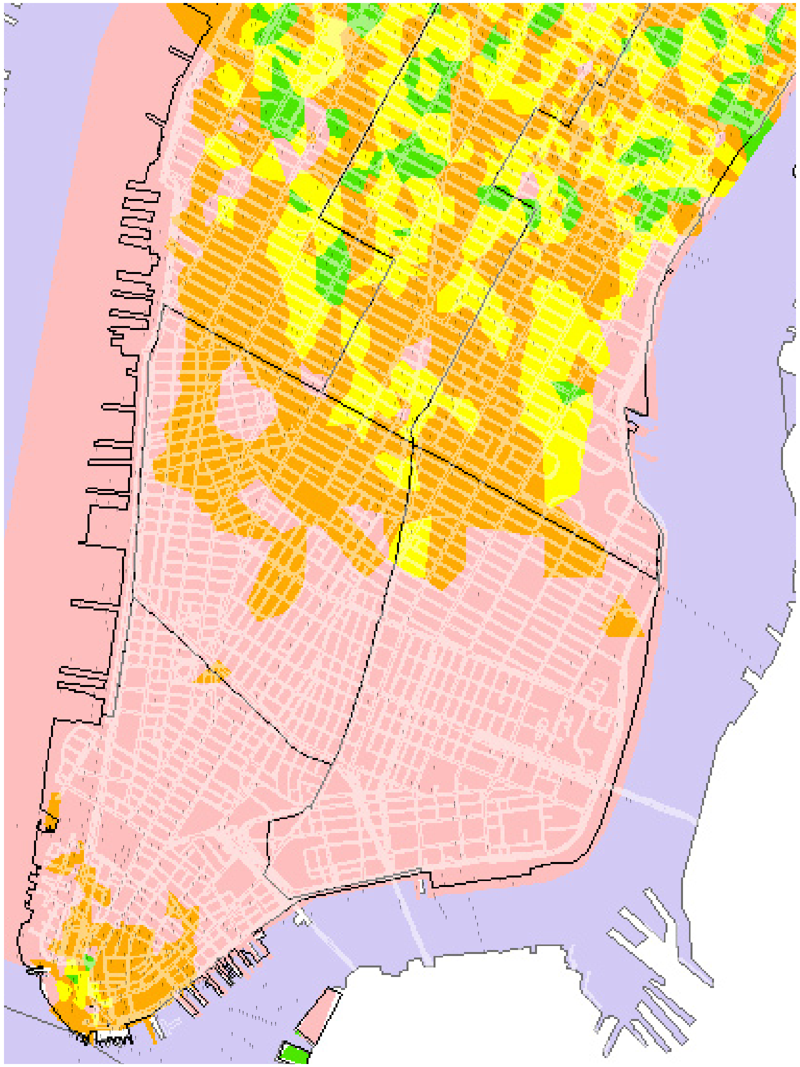


Census-tract-based map of site classes in lower Manhattan using all boring data and additional geological information.

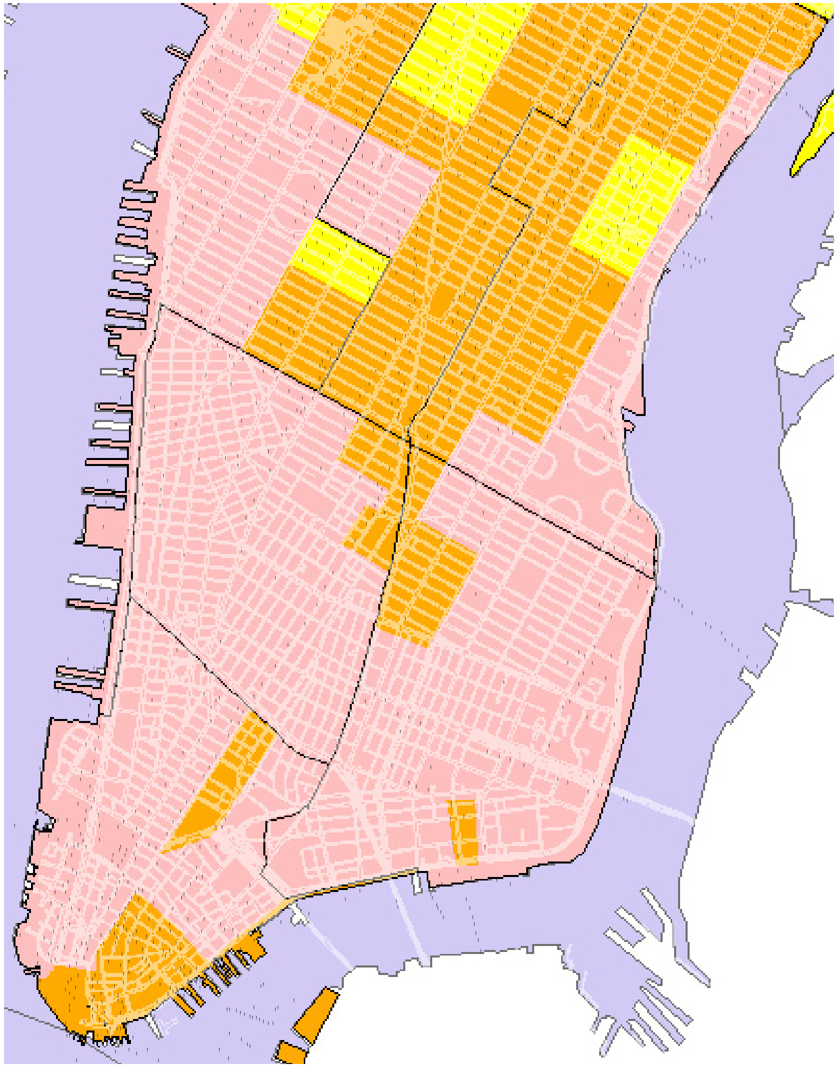


Black dots represent boring data used.

# MAPPING SOIL TYPES IN MANHATTAN



“Thiessen Polygon” map of site classes in lower Manhattan derived from depth-to-bedrock data only.



Census-tract-based map of site classes in lower Manhattan using all boring data and additional geological information.

# EXPECTED GROUND SHAKING

*By analyzing potential ground shaking, we can identify the areas, structures, and systems with highest risk and ultimately help reduce those risks.*

Most damage and loss caused by an earthquake is directly or indirectly the result of ground shaking. By analyzing potential ground shaking, we can identify the areas, structures, and systems with highest risk and ultimately help reduce those risks.

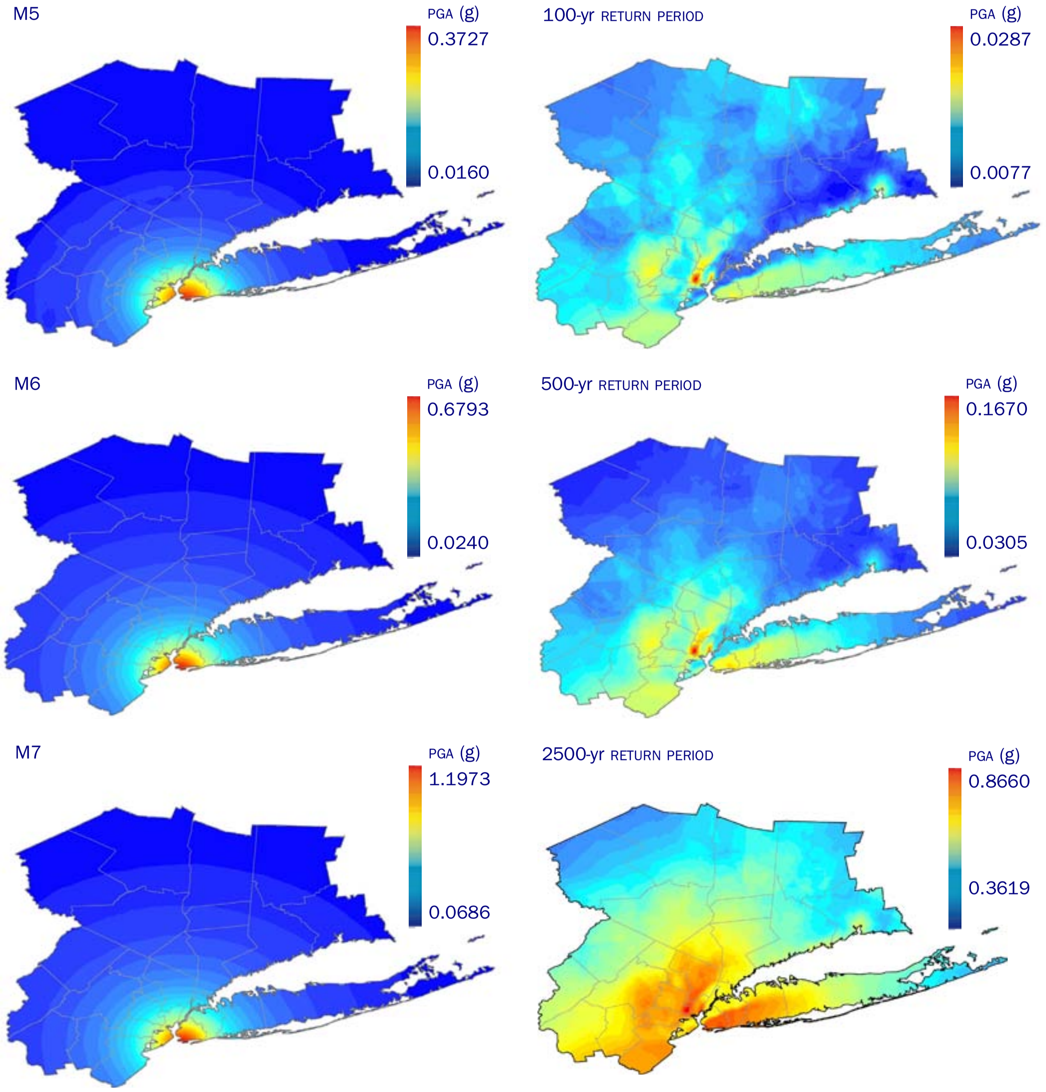
## Peak Ground Acceleration

Ground shaking, or *peak ground acceleration* (PGA), is one of the most important measures used to quantify ground motion. For deterministic scenario events shown on this page (M5, M6, M7), the PGA pattern is based on the location and magnitudes of the scenario earthquake, as well as the local geology. For probabilistic scenarios (100-, 500-, 2500-yr), the PGA levels increase with return period. PGA is a good index of hazard to buildings because there is a strong correlation between it and the damage a building might experience. In this study, attenuation relationships (or how ground motions travel from the source to each building) were used to calculate ground shaking for rock sites (Class B). These relationships were then amplified by factors based on local soil conditions.

## Greatest Chance for Damage

When there is an earthquake, the forces caused by the shaking can be measured as a percentage of the force of gravity, or percent g. The greater the PGA value, the greater the chance for damage. Since for the three deterministic scenarios (M5, M6, M7) lower Manhattan is closer to the earthquake epicenter, the highest ground motions (PGA) are expected in its vicinity.

The figures to the far right illustrate the probabilistic hazard: the largest PGA values (areas in yellow and red) occur generally near the historically largest magnitude earthquakes and in the regions of the softest soils. Note the increase of PGA shaking levels with increasing recurrence periods (from top to bottom right).



Mapping the geographic distribution of ground shaking (PGA) helps identify areas with highest risk.

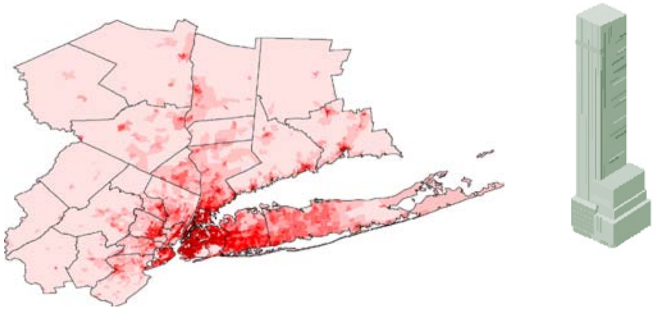
# BUILDING TYPES AND VALUE IN THE REGION

A building's construction is a key factor in how well it can withstand the forces produced by earthquakes.

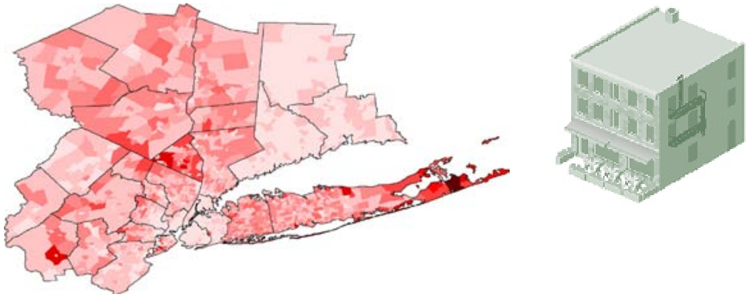
Unreinforced masonry buildings are the most at risk in an earthquake because the walls are prone to collapse outward. Steel and wood buildings have more ability to absorb the energy from an earthquake. Wood buildings with proper foundation ties have rarely collapsed in earthquakes.

The figures on this page show the distribution of each of the primary building types within the study region. For each case, the total replacement values are listed in the upper left corner.

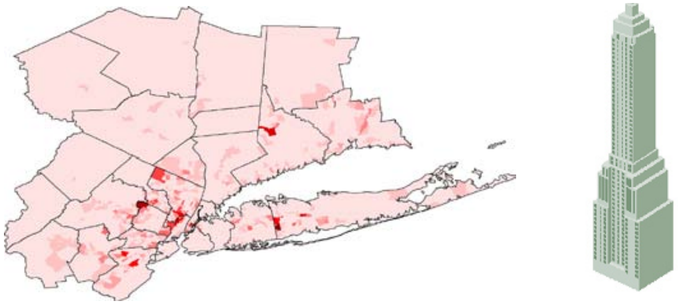
REINFORCED CONCRETE [$50b]



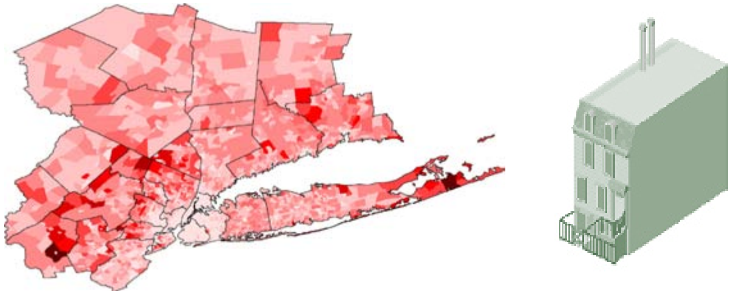
UNREINFORCED MASONRY [$160b]



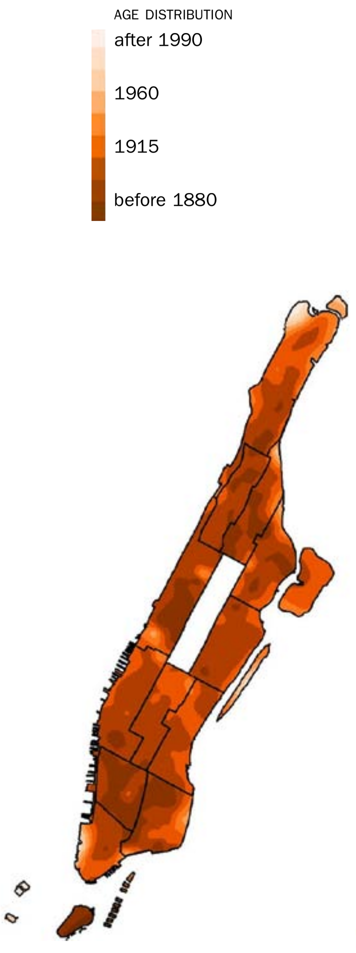
STEEL [$120b]

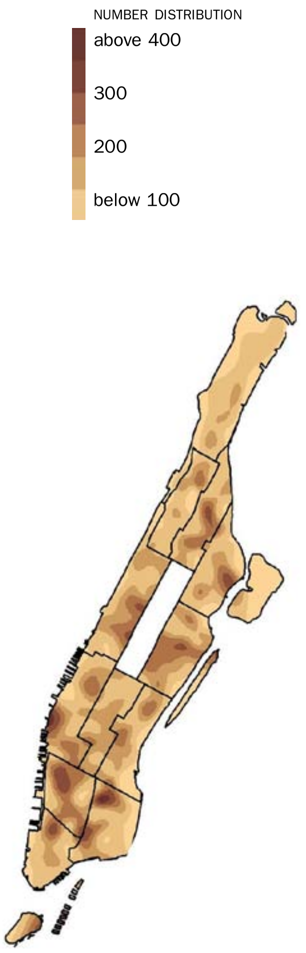


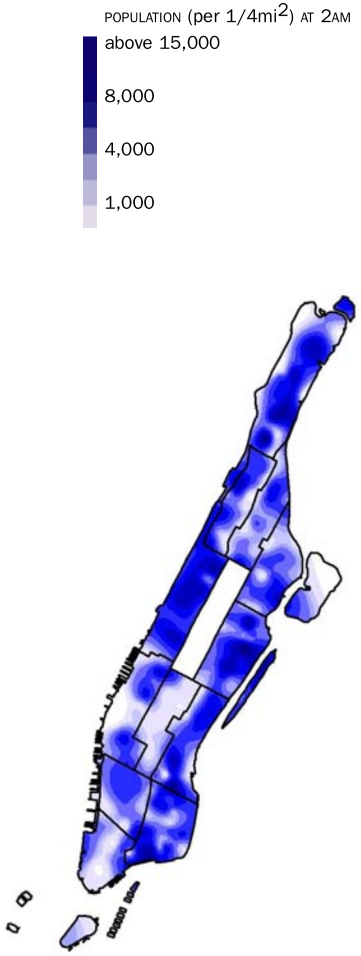
WOOD [$560b]

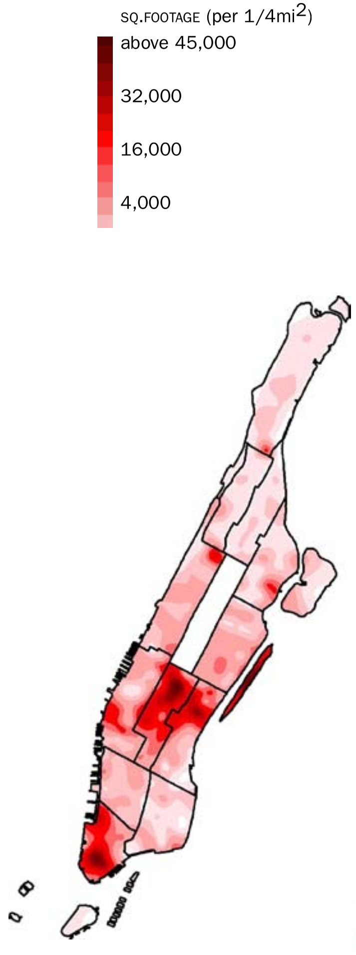


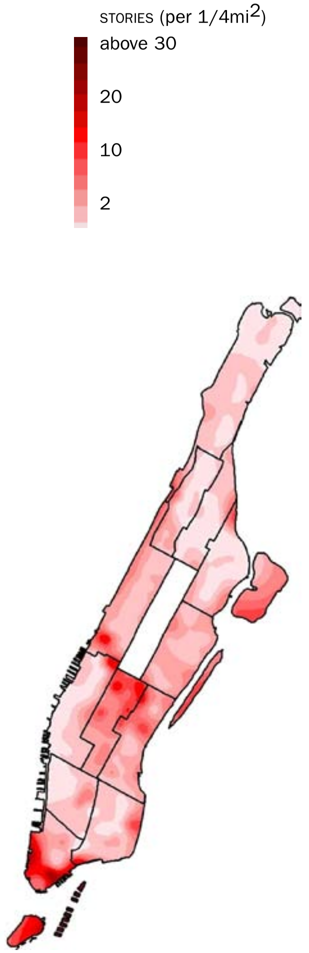
# BUILDING TYPES IN MANHATTAN











Besides type of construction, other building attributes are important (e.g., age, number of stories, quality of construction, etc). Here are some related maps of information for Manhattan.

# BUILDING TYPES IN MANHATTAN NEIGHBORHOODS

***Determining what level of damage buildings experience is the essential component and heart of the loss estimation process.***

Knowing what buildings are made of is a key factor in predicting the level of damage they might sustain in an earthquake. This information is also useful in predicting damage patterns; for example, the most vulnerable building types in a region, or the areas expected to have the most damaged buildings in different scenario earthquakes. In fact, determining what level of damage buildings experience is the essential component and heart of the loss estimation process (which is later used to predict other losses, such as cost and casualties).

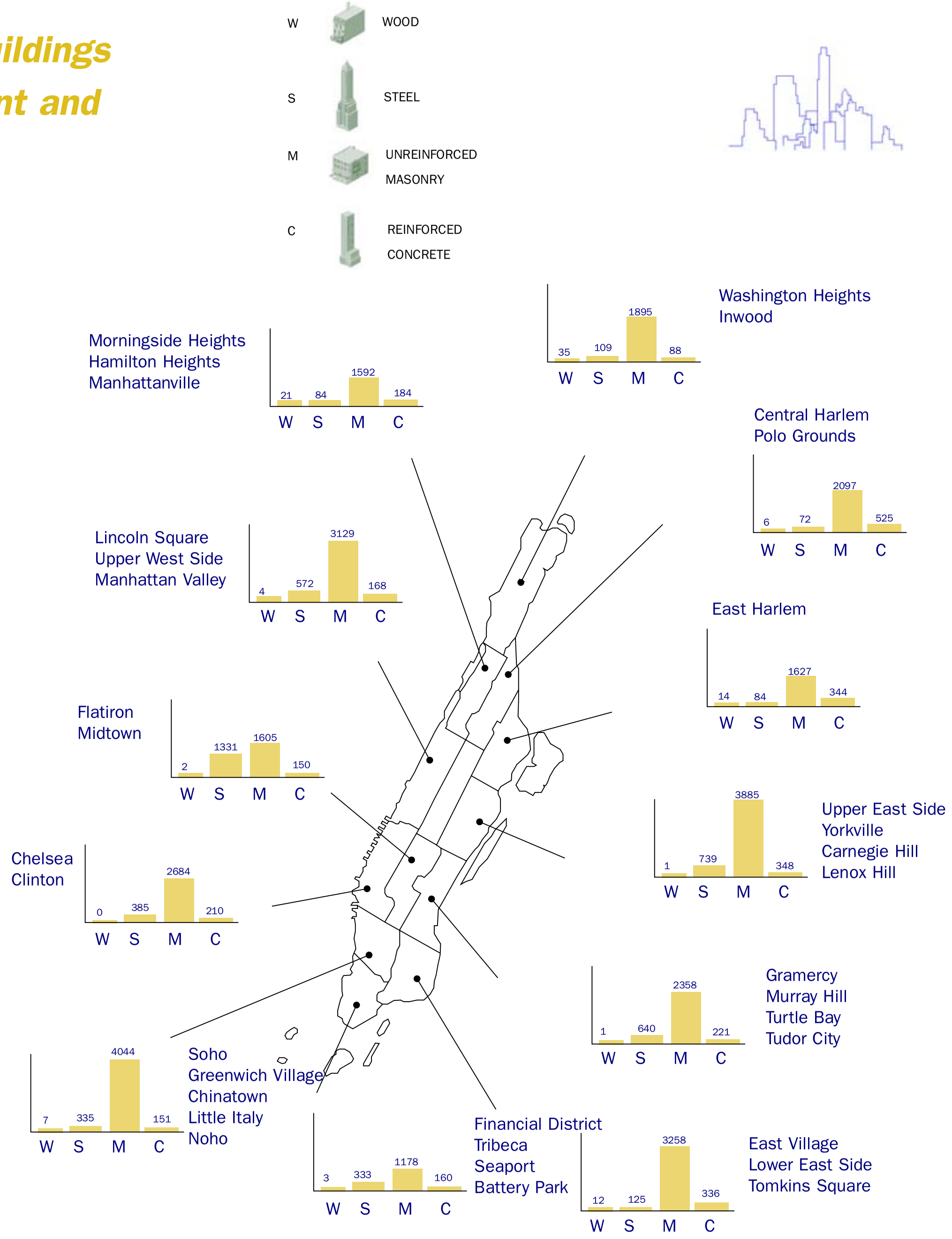
## Building Distribution in Manhattan

The figure on this page shows the relative distribution of the number of buildings in each of these four categories within 12 different neighborhoods in Manhattan. The predominant building types by count are these:

- Unreinforced masonry (M on the bars to the right, totaling 29,352 buildings)
- Steel (S)
- Reinforced Concrete (C)
- Wood (W)

## Problem with Unreinforced Masonry

The results indicate that most buildings (in 9 of 12 Manhattan neighborhoods) are constructed of unreinforced masonry; whereas, there are few wood buildings. Unfortunately, buildings made of unreinforced masonry (URM) are the *most vulnerable* to damage during an earthquake because URM is brittle and does not absorb motion as well as more ductile wood and steel buildings.



# BUILDING DAMAGE IN MANHATTAN

***The most vulnerable district in Manhattan would not be the one closest to the epicenter, but rather the Upper East Side, due to vulnerable unreinforced masonry buildings on soft soils.***

*HAZUS* subdivides building damage into five categories: [1]

- No Damage (N on the figures to the right)
- Slight Damage (S)
- Moderate Damage (M)
- Extensive Damage (E)
- Complete Damage (C)

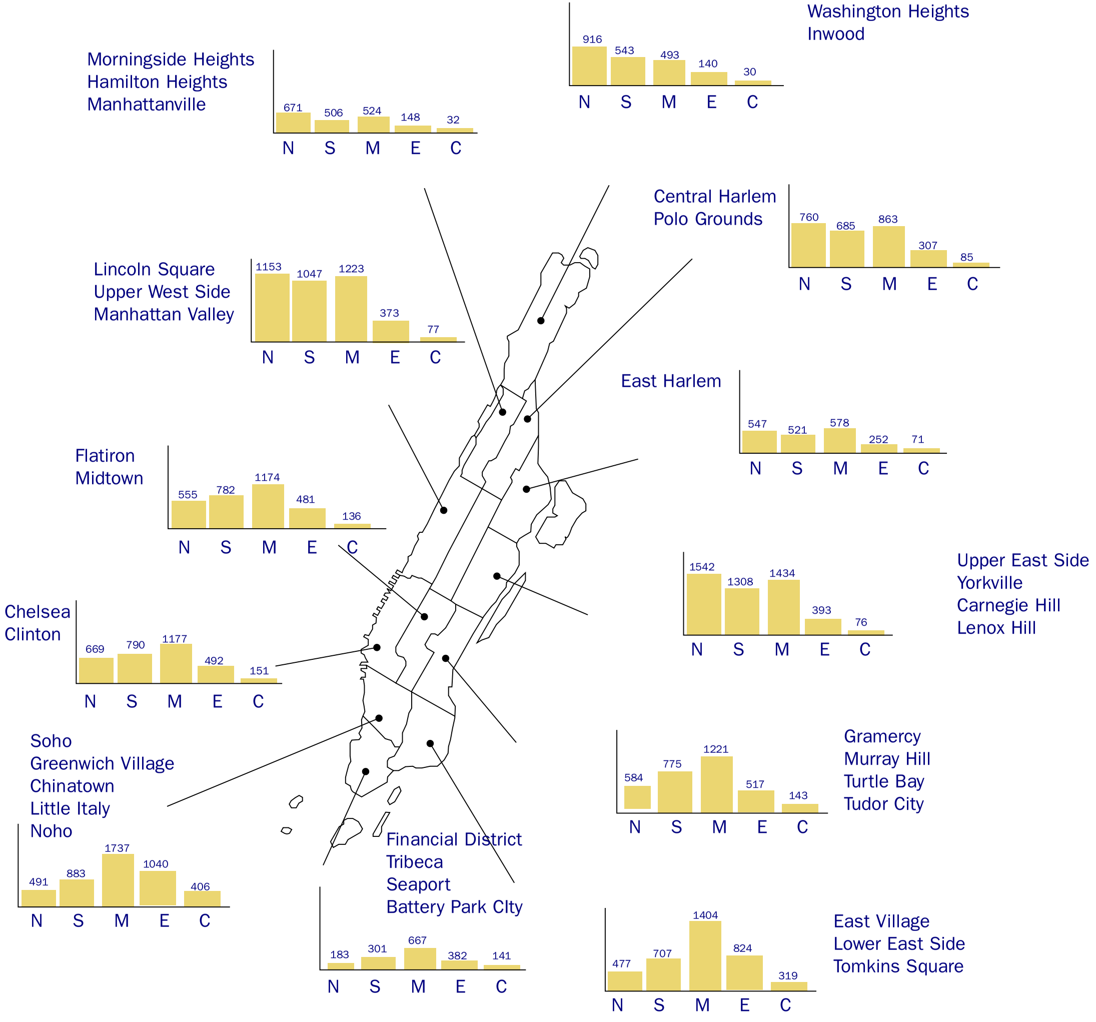
## Manhattan Most at Risk

The figure on this page shows the distribution of damage likely in 12 Manhattan neighborhoods for an earthquake with Magnitude 7.0 intensity, centered at the 1884 historic site. The results indicate that an earthquake of this magnitude and location would result in the collapse or in the imminent danger of collapse of 1,667 buildings in Manhattan (the sum of all bars marked C, on the figures to the right). In this scenario, due to particularly soft soil conditions on the Upper East Side, this location would experience a PGA of 0.49, almost double the PGA that the Financial District would experience, despite being located further from the epicenter. As this area also has a high percentage of unreinforced buildings, it is particularly vulnerable to earthquakes.

## Reasons for Vulnerability

As you can see from the figure to the right, the Upper East Side has the most buildings (4,753, about 13 percent) and the most unreinforced masonry buildings (1,434, also 13 percent). In fact, these buildings account for 18 percent of the total square footage in Manhattan and, therefore, are the most at risk, contributing to a large portion of the total loss in a seismic event. Buildings in Chinatown are also at greater risk for complete collapse as a result of the same two factors: softer soils and the predominance of masonry buildings.

| | |
|---|---|
| N | **NO DAMAGE** |
| S | **SLIGHT DAMAGE**<br>Minor cracks |
| M | **MODERATE DAMAGE**<br>Larger cracks and some connection failures. |
| E | **EXTENSIVE DAMAGE**<br>Although people may escape safely, the building will eventually have to be demolished. Significant cracks and connection failures. |
| C | **COMPLETE DAMAGE**<br>Structure is collapsed or in imminent danger of collapse. Extensive member and connection failures and major foundation cracking. |



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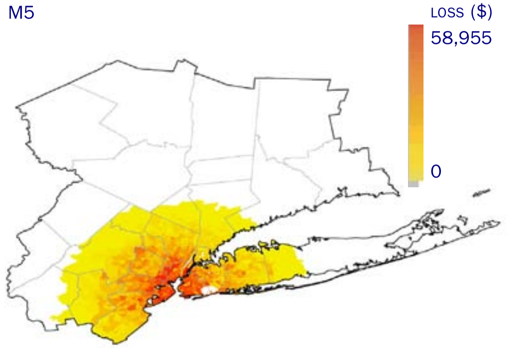
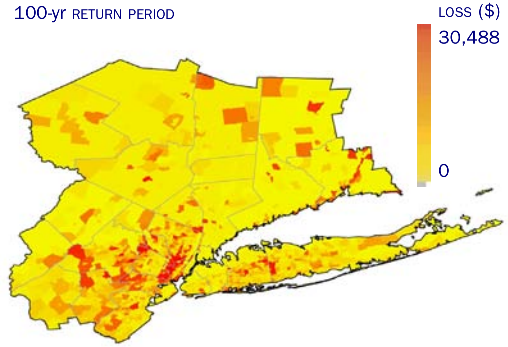
[1] The version of *HAZUS* used in this study (*HAZUS*-SR2) derives the number of buildings in each of the five damage states from the damage state distributions of the total square footage in a census tract. The number of buildings assigned to each category is based on average building square footage size. Consequently, the actual number of buildings assigned to each damage state may be over estimated.

# BUILDING LOSSES IN THE REGION

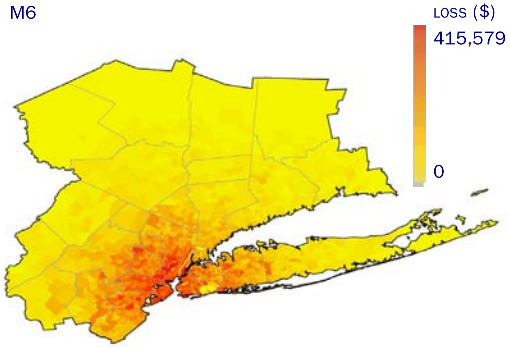
M5



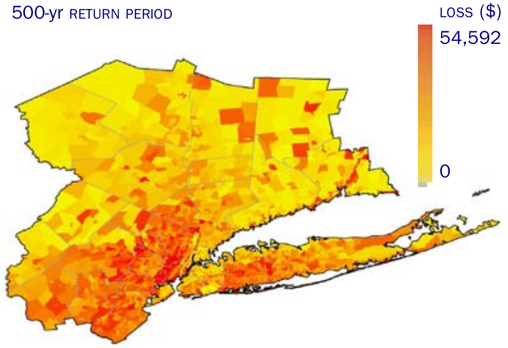
100-yr RETURN PERIOD



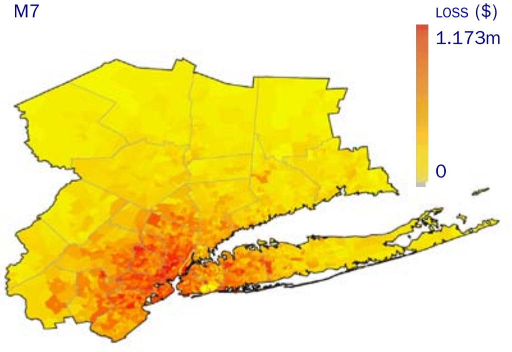
M6



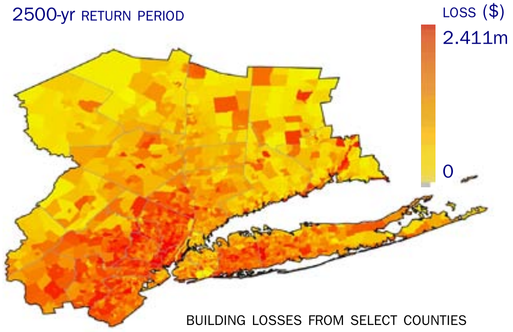
500-yr RETURN PERIOD



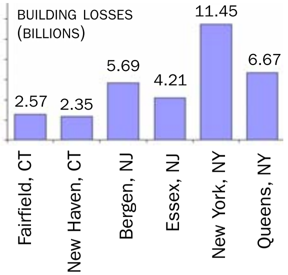
M7



2500-yr RETURN PERIOD



BUILDING LOSSES FROM SELECT COUNTIES (FOR THE 2500-yr RETURN PERIOD)



***Manhattan would experience the greatest building-related loss in the region, estimated at $11.45 billion of about $85 billion for the entire study region.***

The figures to the left summarize the total building-related losses per census tract for the region of study, based on the magnitude of the deterministic scenario earthquakes (M5, M6, M7) or the average return period (100, 500, 2,500 years) for the probabilistic case. The total value listed next to each figure includes both *direct building losses* and building-related business interruption losses:

▸ *Direct building losses* (also known as “capital stock loss”) are the estimated costs to repair or replace the damage caused to the building and its contents.

▸ *Business interruption losses* (also known as “income-related loss”) are financial losses related to the length of time a facility is non-operational, including relocation expenses, loss of services or sales, wage loss, and rental income loss to building owners.

As expected, the total building-related loss estimates are larger for significant events (i.e., those with longer average return periods and/or greater magnitude). Thus, the greatest loss per census tract among all tracts in the region ($2.411 million) occurs for the probabilistic 2,500-year recurrence period, as illustrated in the figure on this page.

## Greatest Losses in New York County

The bar graph on this page indicates that in a 2,500-year event, New York County (Manhattan) would experience the greatest building-related loss in the region, estimated at $11.45 billion. The majority of total losses would be produced by residential structures (roughly 50-60 percent of the total loss estimates, depending on the scenario), which are predominately unreinforced masonry. For the probabilistic 2,500-year recurrence period, the combined building losses ($64.3 billion) and income losses ($20.4 billion) for the entire 31-county, Tri-State region could amount to $84.8 billion, and for the M7 deterministic scenario event, the expected loss could amount to $196.8 billion, as stated in the “Key Findings” of this report.

# INJURIES

***In moderate earthquakes, most injuries are caused by people falling or being struck by falling objects.***

In moderate earthquakes, many more buildings are damaged than destroyed. This damage to buildings and their contents causes most injuries. For example, in the 1989 Loma Prieta earthquake in California (M6.9 southeast of San Francisco, near the Loma Prieta peak in the Santa Cruz Mountains), 95 percent of the injuries did not involve structural collapse. They were caused by people falling or being struck by falling objects. In fact, most earthquake-related injuries often result from non-structural damage, such as light fixtures falling.

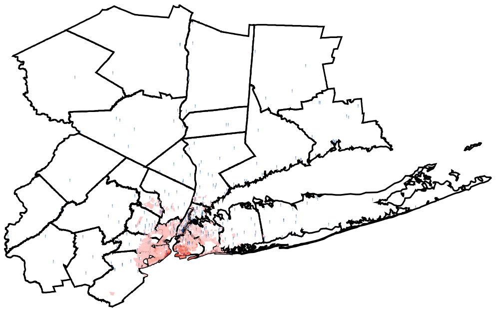
## How Injuries Are Estimated

The methodology for determining injuries and casualties is based on the strong correlation between building damage (both structural and non-structural) and the number and severity of casualties. In smaller earthquakes, non-structural damage will most likely control the casualty estimates. In severe earthquakes, where there will be a large number of collapses and partial collapses, there will be a proportionately larger number of fatalities.

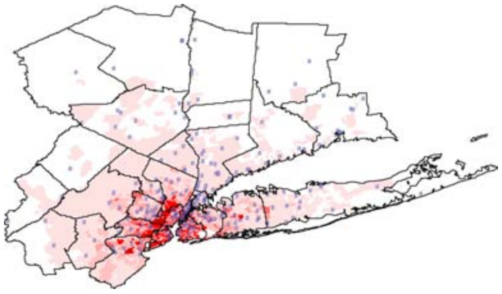
## Injuries in the Region

The figures on this page provide injury estimates for the different earthquake scenarios in the entire NY-NJ-CT region, occurring at 2 pm. As expected, a proportionately larger number of injuries (compared to deaths) occur (e.g., 13,171 for a M7 quake, which is about the size of the Loma Prieta event). The color code indicates that the highest number of injuries would be concentrated in the New York City metropolitan area due to high population concentration.

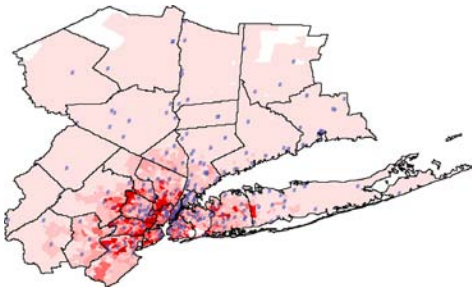
M5 [24 people]



M6 [2,296 people]

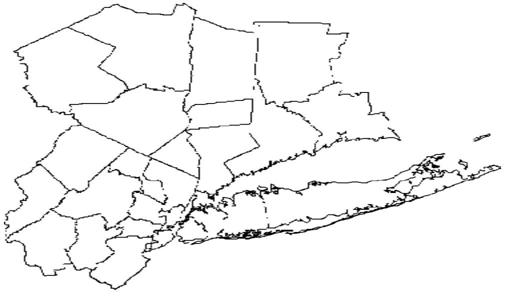


M7 [13,171 people]

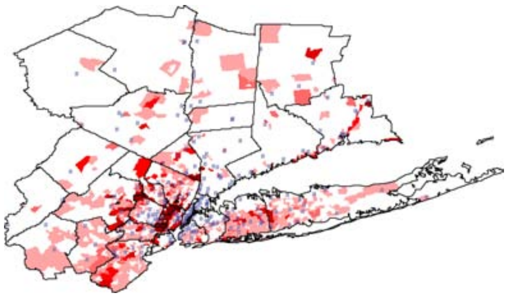


The number of injuries listed at each figure is the total for the entire region.

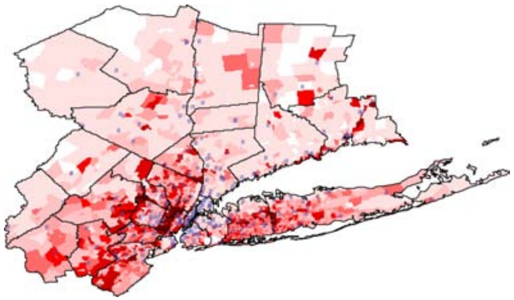
100-yr RETURN PERIOD [0 people]



500-yr RETURN PERIOD [28 people]



2500-yr RETURN PERIOD [1,430 people]



These figures show the concentrations of people that are injured or require hospitalization directly after an earthquake occurring at 2 pm. The blue dots indicate major medical facilities (hospitals).

***Most deaths would be concentrated in the densely populated New York City metropolitan area.***

Building damage has short and long-term implications. In the short term, people may be injured or killed by falling objects. However, most deaths occur in earthquakes when structures collapse. In fact, all of the 63 deaths in the 1989 Loma Prieta, CA earthquake resulted from structural collapse. The second major cause of death in earthquakes is fire.

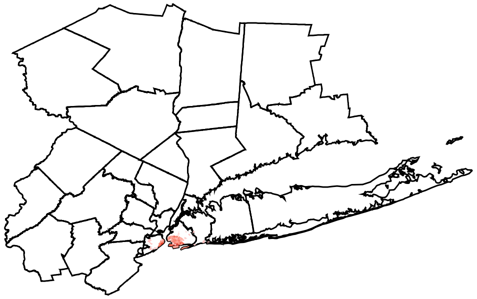
## How Casualties Are Estimated

To estimate the number of casualties for the earthquake scenarios in our study, we used *HAZUS* software to predict the number of casualties at different times of the day; namely, 2 am (when people are asleep and at home), 2 pm (when people are at work), and 5 pm (when most people are commuting). Because of commuting and variations in regional population during the day, people are exposed to different structures of varying vulnerability. Consequently, fatality and injury estimates will vary, depending on the time of day.

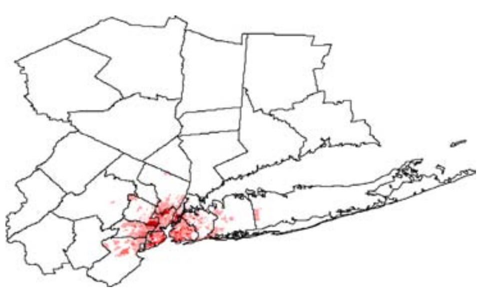
## Casualties in the Region

Our results indicate that a 2 pm earthquake would result in more injuries and deaths, with 5 pm slightly fewer, and 2 am fewest. In a M7 event (about the size of the Loma Prieta, CA earthquake in 1989), there would be an estimated 6,705 deaths in the region, due primarily to structural collapse. Most deaths would be concentrated in the densely populated New York City metropolitan area.

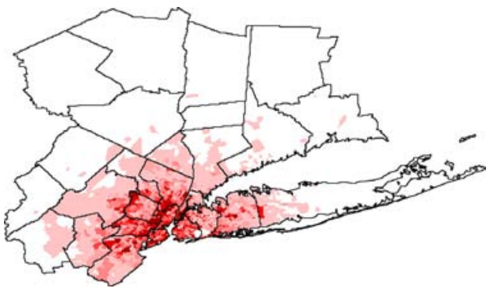
M5 [13 people]



M6 [1,170 people]

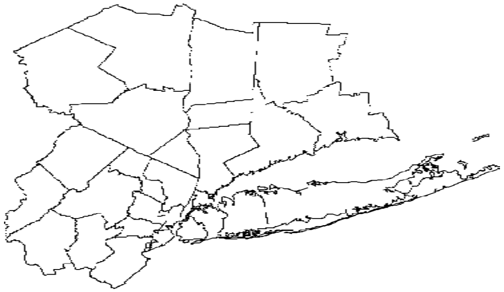


M7 [6,705 people]

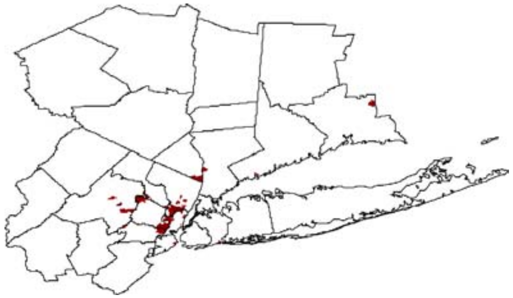


The number of casualties listed at each figure is the total for the entire region.

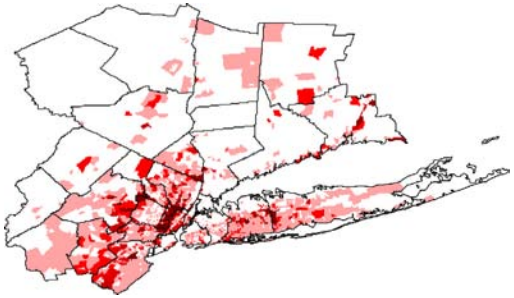
100-yr return period [0 people]



500-yr return period [14 people]



2500-yr return period [727 people]



These figures show the concentrations of deaths directly after an earthquake occurring at 2 pm.

# SHELTER

***Even in a moderate M6 earthquake, nearly 200,000 people in the region would be temporarily dislocated and require shelter.***

As mentioned previously, ground shaking can cause massive and immediate financial losses, casualties, disruptions in critical facilities and services, and severe long-term economic and social losses. Estimates of the number of people requiring shelter following an earthquake are classified as "social losses" within the *HAZUS* model. Whether long-term or short-term, these "social losses" are often missing from other attempts to measure earthquake losses; however, *HAZUS* provides the capability to include shelter requirements for displaced people in our loss estimations.

## Long-term Shelter

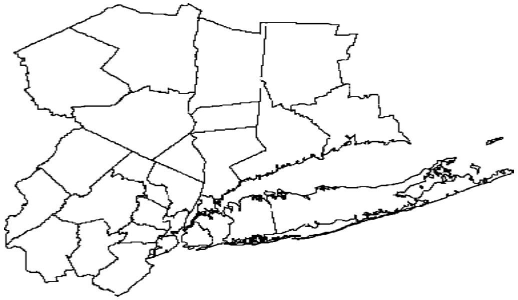
Low-income populations may be the most severely affected, since they have fewer means for relocating to new housing if their residences are damaged. Therefore, homelessness and dislocation may increase, creating long-term shelter needs.

## Short-term Shelter

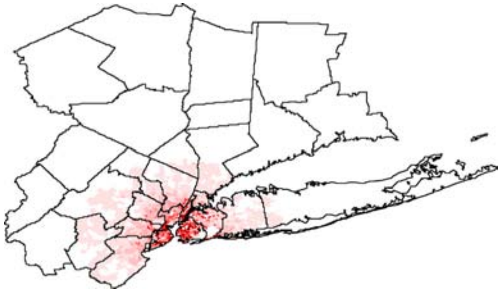
The maps on this page illustrate the concentrations of short-term shelter needs for various earthquake scenarios.  As you can see, even in a moderate M6 earthquake, nearly 200,000 people in the region would be displaced and require shelter. The greatest need for short-term shelter would be in the densely populated areas around Manhattan. The ability to shelter people would be extremely taxed, requiring the use of unconventional facilities, shelter outside the region, and maximum use of available spaces.

M5 [2,800 people]

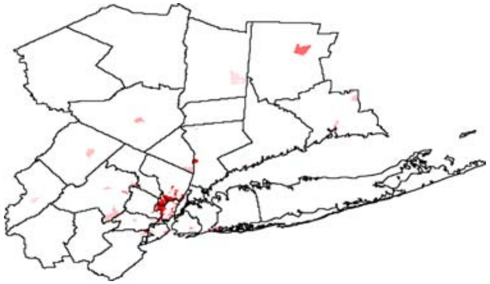
100-yr RETURN PERIOD [0 people]



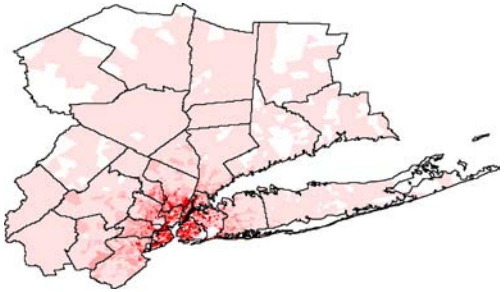
M6 [197,705 people]



500-yr RETURN PERIOD [575 people]



M7 [766,746 people]



These figures show the concentrations of short-term shelter needs for different earthquakes.

## SHELTER (cont.)

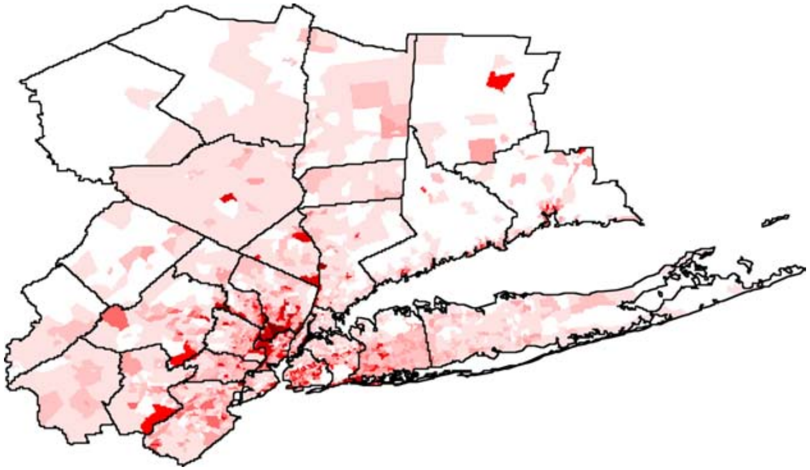
**The projected functionality of schools to provide temporary shelter after a 2,500-year earthquake may be inadequate.**

### Temporary Public Shelter

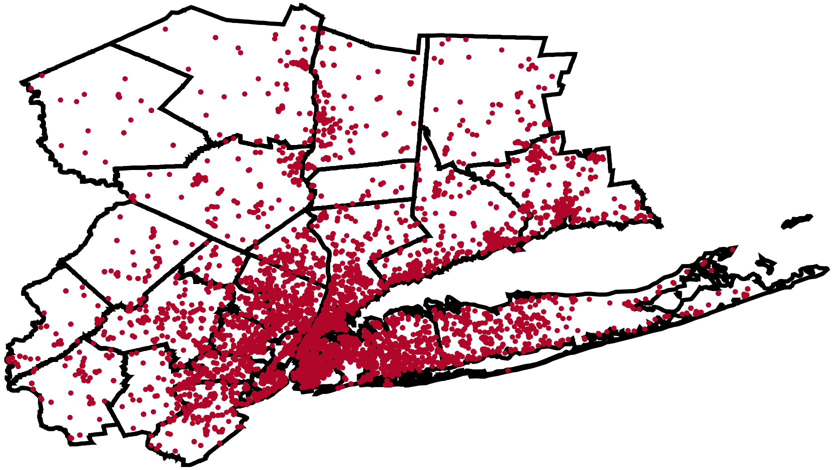
Schools often serve as temporary public shelters in emergencies. However, to be suitable as public shelters, they must be able accommodate the displaced population. Our projections for a Magnitude 5 event show that about 2,800 people in the region would need shelter, and the available temporary public shelters could accommodate them.

However, for M6 and M7 events and for scenario return periods greater than 500 years, which have larger shelter needs and very low school functionality, the region would not be able to accommodate the demand for shelter. More specifically, in a 2,500-year event (the so-called "maximum considered earthquake"), an estimated 84,626 people would require short-term shelter in the existing 6,466 schools, identified on the adjacent figure. In a damaging earthquake, therefore, the region could not accommodate the displaced population.

2500-yr RETURN PERIOD [84.626 people]



SCHOOLS [6,466 for shelter]



These figures show the concentrations of short-term shelter needs for the 2500-year return period scenario (the so-called "Maximum Considered Earthquake"). The figure to the right shows the locations of schools within the region which would likely be used for these shelter needs.

# CRITICAL FACILITIES

*Critical facilities support vital response activities to aid the victims of an earthquake.*

After an earthquake, people are at their most vulnerable state. Collapsed and burning buildings, spreading fires, homelessness, and social chaos are just a few examples of secondary crises that follow in the wake of an earthquake and magnify its effects. In these critical moments, earthquake response is crucial.

## First Responders

The fire department must be able to fight the flames that erupt. Hospitals must be prepared to treat the potential influx of injured. The police must ensure social order and facilitate urban search and rescue activities to save as many lives as possible. Schools must be open to provide temporary shelter. These facilities are *critical* to the efficient and effective management of scarce resources in a disaster situation and must remain functional.

## The Role of Critical Facilities

*Critical facilities* are those facilities that must remain in operation after an earthquake for response operations (e.g., hospitals, police/rescue stations, fire stations). These facilities provide required services to victims of an earthquake and are primarily responsible for the rate of recovery in the affected area. Thus, to be effective, the structures containing these facilities must remain fully functional and structurally sound. The structure's ability to function is directly related to its particular damage state (in other words, slightly damaged facilities will still be able to aid in recovery operations while those that are extensively damaged cannot).

Losses to critical facilities in an earthquake (or any other disaster) will have a magnifying effect on loss estimations in both economic terms and in human lives. Not only must the estimate include the cost of the facility itself, but also losses for all the victims in its service area.

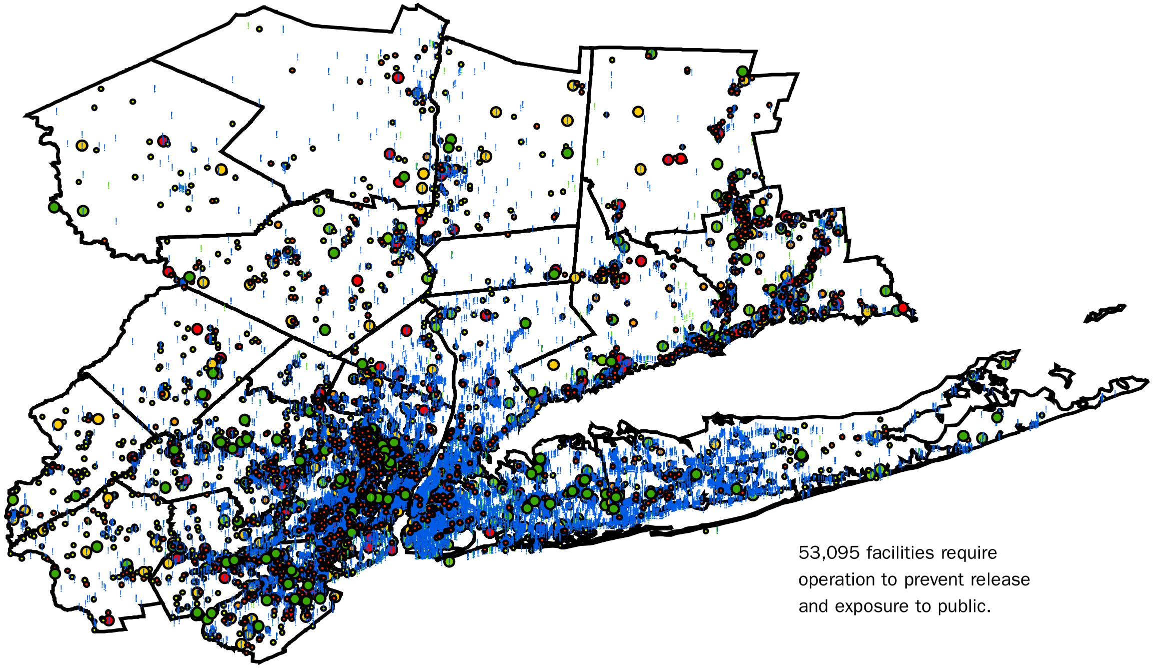
While support services from outside the affected region can be moved to aid in the response efforts, the total loss resulting from an earthquake will be controlled by the reliability of the critical facilities within that region.

## Hospitals in the Region

In assessing the vulnerability of critical facilities in the region, we considered the number of hospital beds (86,272), and their location (see figure on next page). Our results indicate that hospital functionality would be adequate for most scenarios, except for a M7 event, in which the estimated 13,171 injured (more than double 9/11), would require 26 percent more than the available number of beds. Patients would need to be transported to hospitals outside the affected region.

# CRITICAL FACILITIES (cont.)

HAZARDOUS MATERIAL SITES [53,095 facilities]



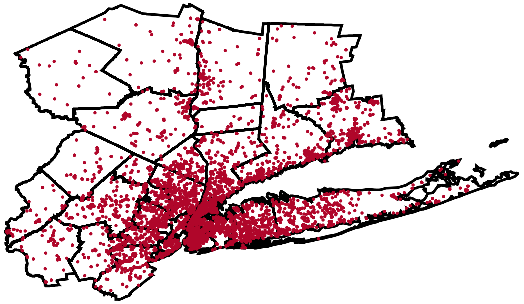
53,095 facilities require operation to prevent release and exposure to public.

## Toxic Release

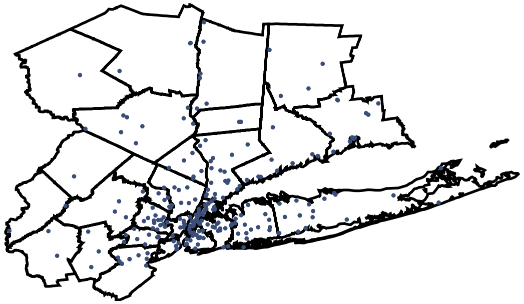
In the NY-NJ-CT region, there are 53,095 hazardous material sites. The approximate location of each site is shown on the map above, which was generated using the Toxic Release Inventory (TRI). The TRI is a database that contains information concerning specific toxic chemical releases, transfers, waste management, and pollution prevention activities from manufacturing facilities throughout the United States. The inventory was established under the Emergency Planning and Community Right-to-Know Act of 1986 (EPCRA), passed by Congress to promote planning for chemical emergencies, and to provide information to the public about the presence and release of toxic and hazardous chemicals in our communities.

As you can see, there are thousands of hazardous materials sites in the NY-NJ-CT region. If these sites were damaged in an earthquake, the public risks exposure to a toxic release, resulting in a chemical emergency.

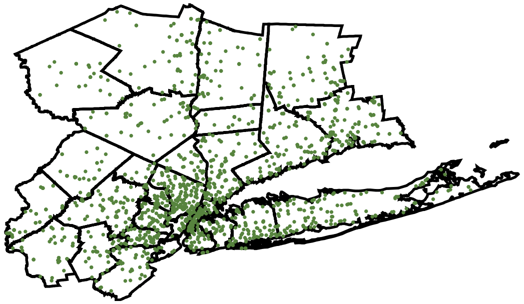
SCHOOLS [6,466 for shelter]



HOSPITALS [86,272 beds]



POLICE STATIONS [744 for rescue]



In a Magnitude 7 earthquake, critical facilities in the region would not be able to accommodate the demands on available resources.

***Typically, the first 24 hours after an earthquake are the most critical for rescue operations to save lives and mitigate serious injuries.***

FUNCTIONALITY AT DAY ZERO (%)

★ 0-10
★ 10-20
● 20-50
●
●
● above 50
•
• above 70

DISTANCE TO NEAREST FACILITY

4000 m

0 m

Dot indicates 5 persons in need of a hospital. Star indicates hospital with low functionality.

Typically, the first 24 hours after an earthquake are the most critical for rescue operations to save lives and mitigate serious injuries. To complicate matters, if the structural and nonstructural components of the hospital are heavily damaged, then the population must find alternative facilities in other accessible regions, or forego treatment. Because of transportation difficulties and overwhelmed medical facilities, the affected population would face an increased risk of casualties.

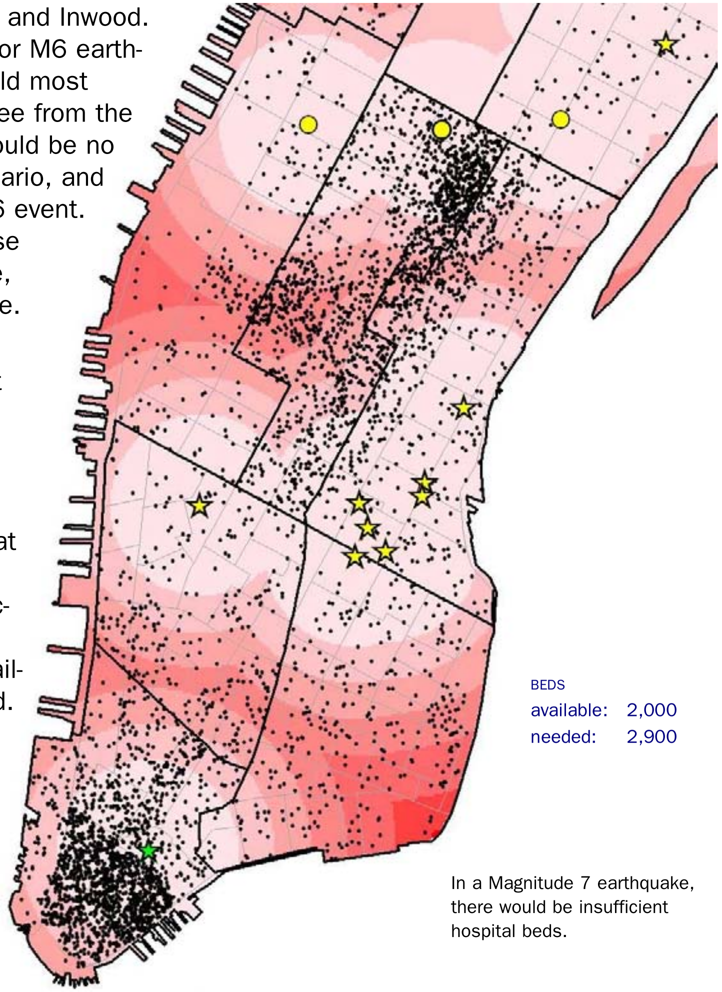
## Hospital Beds Available in Manhattan

The figures that follow show the functionalities of the 20 major medical facilities in Manhattan (about 10,000 beds) with contours that represent the distance to the nearest hospital for those located in each contour range. The figures also indicate the number of people (dots on the map) who would most likely need medical care at a hospital, based on distance to the nearest major medical facility.

## Hospital Beds Needed

Most of the areas of Manhattan are within 300 meters of major medical facilities, with the exception of the Upper West Side and portions of Washington and Inwood. Consequently, in a Magnitude 5 or M6 earthquake, hospital functionality would most likely be adequate. As you can see from the maps on the next page, there would be no shortage of beds in the M5 scenario, and only 200 more needed for an M6 event. The scenarios considered in these cases are for a 2 pm earthquake, the worst-case time of occurrence.

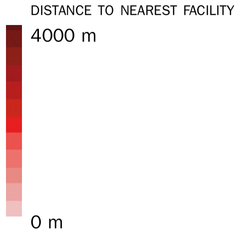
However, as the scenario event becomes larger throughout the region, hospital functionality decreases dramatically. For example, in a Magnitude 7 scenario (shown on this page and the next), our results indicate that there would be an insufficient number of beds (26 percent functionality) for that scenario. Even though 2,000 beds would be available, 900 more would be needed.

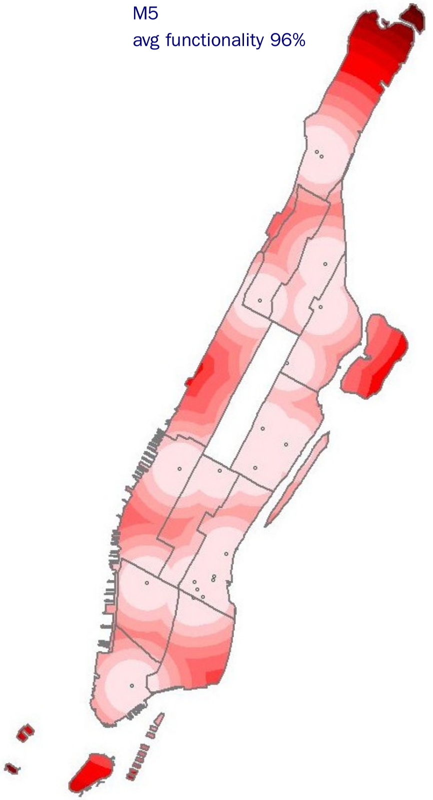


BEDS
available: 2,000
needed: 2,900

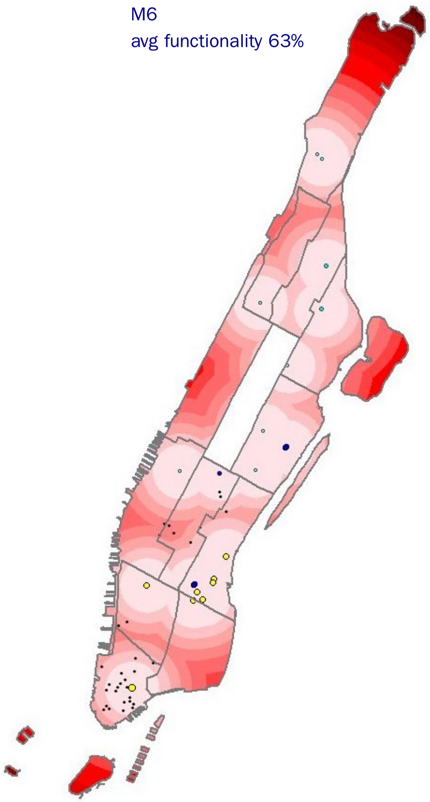
In a Magnitude 7 earthquake, there would be insufficient hospital beds.

## Hospital functionality is most likely adequate for all scenarios except Magnitude 7 earthquake.

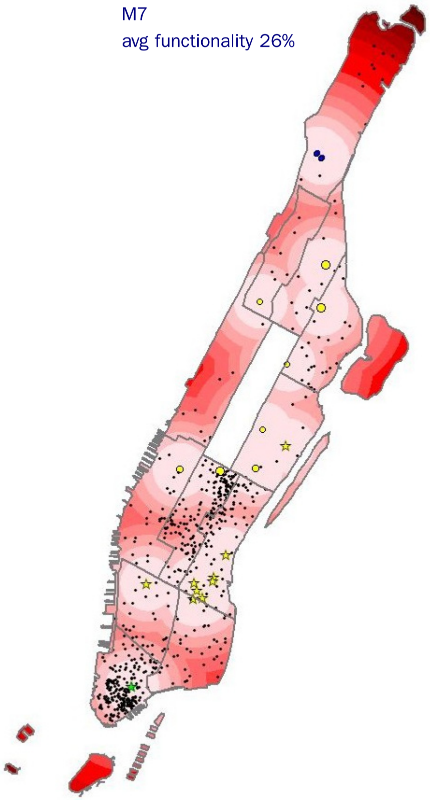



M5
avg functionality 96%

BEDS
available: 9,300
needed: 0


M6
avg functionality 63%

BEDS
available: 6,100
needed: 200


M7
avg functionality 26%

BEDS
available: 2,000
needed: 2,900

## POLICE STATIONS

**In regions with heavy damage to police stations, impaired police activity could potentially result in looting and other crimes.**

In regions with heavy damage to police stations, impaired police activity could potentially result in looting and other crimes. Police inability to respond would also yield increased social losses in the form of social and economic disruption.

### Rescue Facilities Available in Manhattan

The figures that follow show the functionalities of the 36 major emergency rescue facilities in Manhattan (which include police stations) with contours representing the distance to the nearest police station for those located in each contour range. The figures also show the number of people (dots on the map) that would most likely need rescue.

### Rescue Facilities Needed

The scenarios considered in these cases are for a 2 pm earthquake, the worst-case time of occurrence. According to our estimates, rescue functionality would most likely be adequate in a Magnitude 5 or M6 earthquake. However, as the scenario event becomes larger, rescue functionality decreases dramatically, particularly for the M7 event (shown on the next page) and the 2,500-year return period (not shown), both of which would reduce police station functionality to 4 percent. Fire departments and urban search and rescue teams would be critical for rescue operations.

FUNCTIONALITY AT DAY ZERO (%)
- ★ 0-10
- ★ 10-20
- ● 20-50
- ● above 50
- ● above 70

DISTANCE TO NEAREST FACILITY
4000 m
0 m

Dot indicates 1 person in need of rescue. Star indicates police station with low functionality.

This close-up view of Manhattan shows that in a Magnitude 7 earthquake, police activity would be severely impaired.

# POLICE STATIONS (cont.)

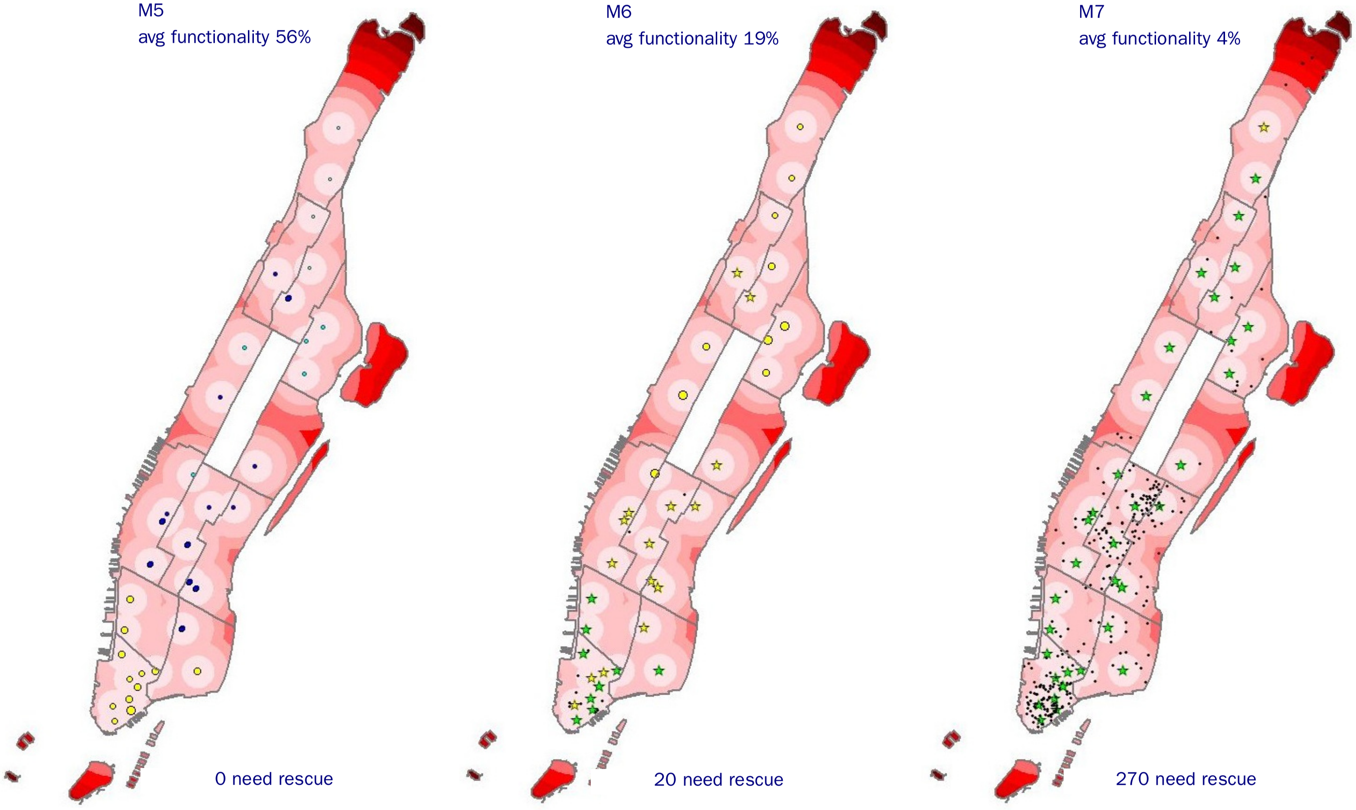
DISTANCE TO NEAREST FACILITY

4000 m

0 m

Dot indicates 1 person in need of rescue. Star indicates police station with low functionality.

## *Rescue functionality is most likely adequate for all scenarios except Magnitude 7.*



M5
avg functionality 56%

0 need rescue

M6
avg functionality 19%

20 need rescue

M7
avg functionality 4%

270 need rescue

# FIRE STATIONS

*In a larger earthquake, as many as 900 fires could break out simultaneously, requiring more than the available water supply.*

Historically, large magnitude earthquakes have resulted in significant damage and loss of life due to structural failure. However, in many instances, even greater property damage was caused by fire damage, related indirectly to the seismic event. For instance, the fires resulting from the 1906 San Francisco earthquake destroyed more of the city than the actual earthquake. Seismic damage rendered the water systems and fire fighting units inoperable. While the primary cause of death is structural collapse, the second most significant cause of fatalities is fire.

## Severity of Fires

The severity of fires following an earthquake can be affected by many factors: ignition sources, types and density of fuel, weather conditions, functionality of water systems, and the building's susceptibility to fire. A complete model of a fire after an earthquake requires extensive input with respect to the level of readiness of local fire departments, as well as the types and availability (functionality) of water systems.

## Fire Stations Available in Manhattan

The figures that follow show the functionalities of 54 major fire stations with contours that represent the probable gallons-per-minute (GPM) demand of the fires for scenarios M5, M6, and M7. These figures also show relative locations of probable ignitions and the number of people that would most likely be exposed to those fires.

## Water Capacity Needed

As a rule, larger scenarios indicate more likely fires and a greater chance that the fire stations would have limited functionality and would not be able to supply the GPM needed to suppress the fires. For example, in the M7 scenario, demand is more than 14 times the available water supply. That scenario also has the largest amount of property and people exposed ($15.2 billion and 69,000, respectively).

According to our estimates, although the number and relative placement of fire stations in Manhattan seems reasonable, the vulnerability and capacity of these structures may not be adequate for larger events (M6 or 2,500-year), where as many as 900 fires could break out simultaneously in the Tri-State region, requiring more than the required gallons-per-minute to fight them.

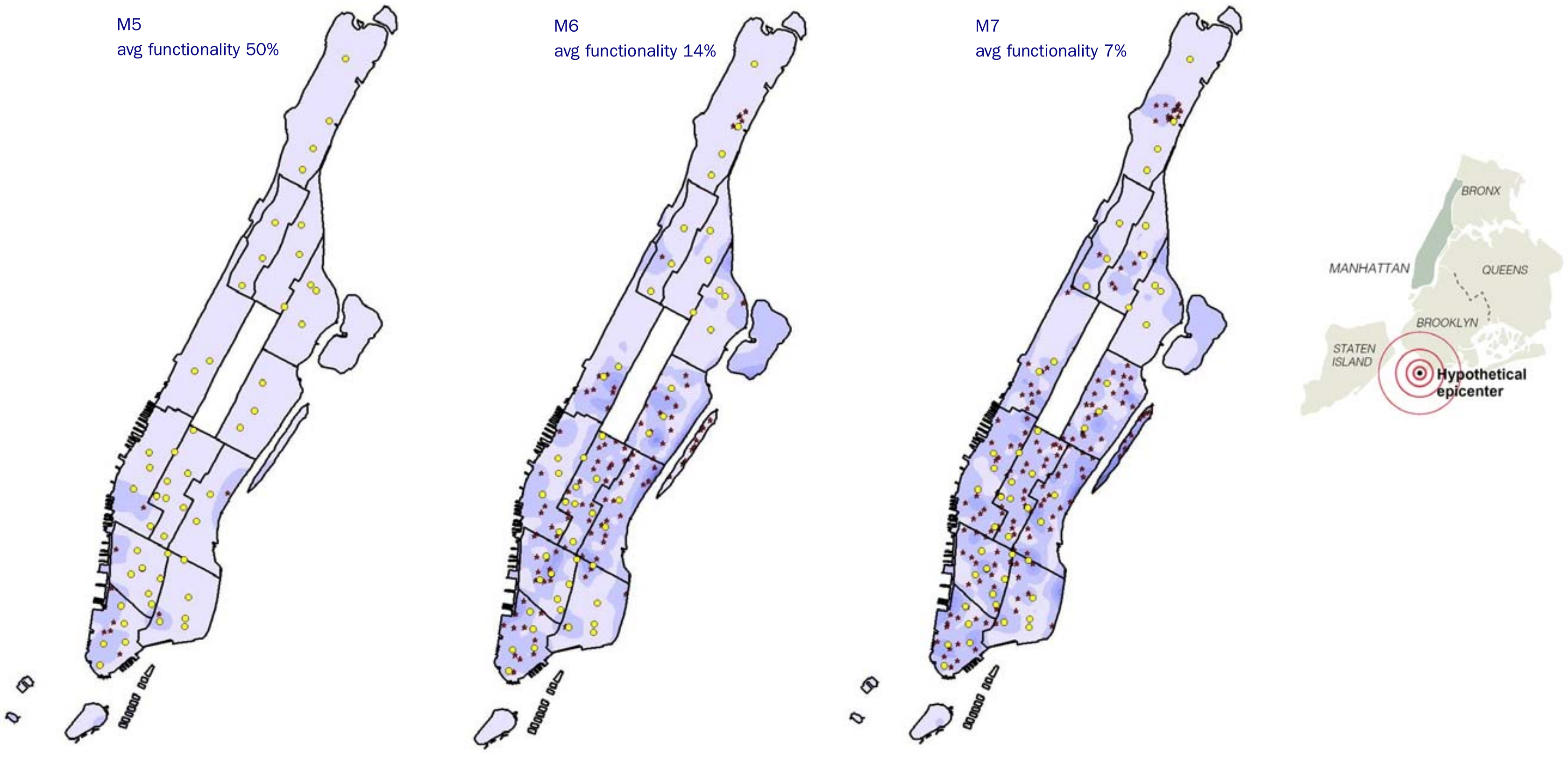
# FIRE STATIONS (cont.)

FUNCTIONALITY AT DAY ZERO (%)
- ★ 0-10
- ★ 10-20
- ● 20-50
- ●
- ●
- ● above 50
- ●
- ● above 70

WATER DEMAND [GPM]
4000
0

Red star indicates 1 fire.

***These sets of figures indicate that although the number and relative placement of fire stations seem reasonable, the vulnerability and capacity of these structures may not be adequate for larger events.***



M5
avg functionality 50%

10 ignitions
0.1x capacity

M6
avg functionality 14%

110 ignitions
5x capacity

M7
avg functionality 7%

170 ignitions
5x capacity

# DEBRIS

## An estimated 1.6 million tons of debris would be generated from an M5 earthquake in the region, equal to the 1.6 million tons of debris generated by the terrorist attacks on 9/11.

Like fire, debris is considered an induced hazard or secondary effect of an earthquake. Using *HAZUS*, we were able to estimate the total amount (in thousands of tons) of debris generated by the scenario earthquakes. The debris estimates are based on ground motion parameters (PGA, PGV, etc.) and on all building types. The greatest amounts of debris correspond to damage estimates where the PGA is highest and unreinforced masonry is most concentrated. Although this is a unique application of the software, its empirical approach has proven quite useful in estimating debris totals.

*HAZUS* classifies debris into two types:

- Debris that falls in large pieces, such as steel members or reinforced concrete elements. These require special treatment to break into smaller pieces before they are hauled away.
- Debris that is smaller and more easily moved with bulldozers and other machinery and tools, including brick, wood, glass, building contents, and other materials.

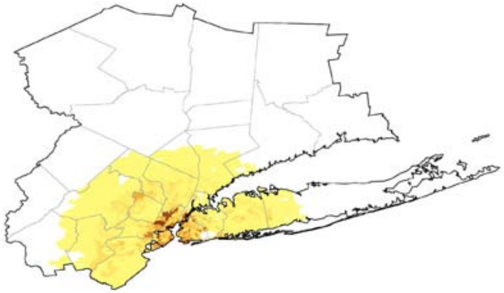
### Debris in the Region

The debris estimates for the scenario events in the Tri-State region (shown on this page) include both types of debris (total tons) that would be generated. The results suggest that in a moderate M5 earthquake, an estimated 1.6 million tons of debris would be generated in the region, equal to the 1.6 million tons of debris generated by the terrorist attacks on 9/11. This quantity would be about 21 times greater (34 million tons) in the 2,500-year return-period scenario, the so-called "maximum considered earthquake."

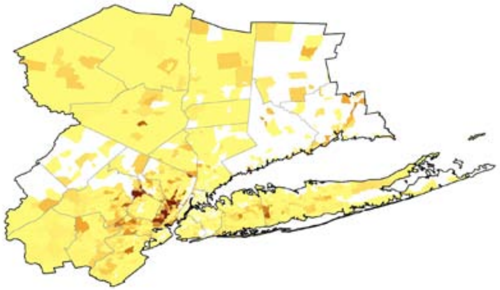
### Debris in Manhattan

The maps on the next page provide detailed estimates for Manhattan. Even in a moderate M5 earthquake, there would be an estimated 88,000 tons of debris (10,000 truckloads), which is 136 times the garbage cleared in Manhattan on an average day. For the M5, M6, M7 scenarios, the debris would be concentrated in Midtown and Gramercy. For 100, 500, 2,500-year return periods (not shown), the debris would be concentrated in northern Manhattan, specifically Washington Heights.

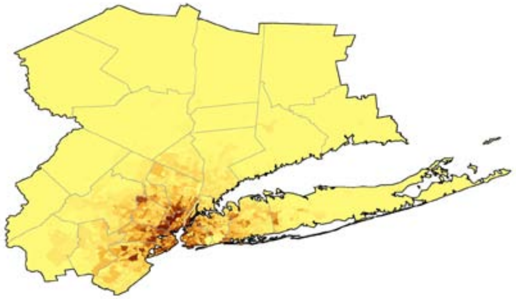
M5 [1.6 million tons]



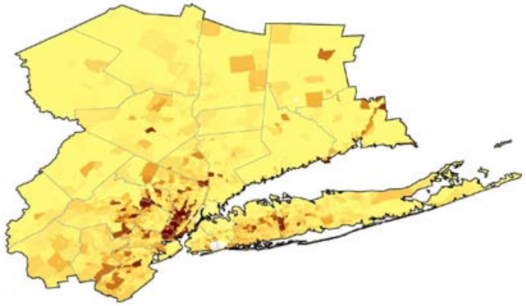
100-yr RETURN PERIOD [0.2 million tons]



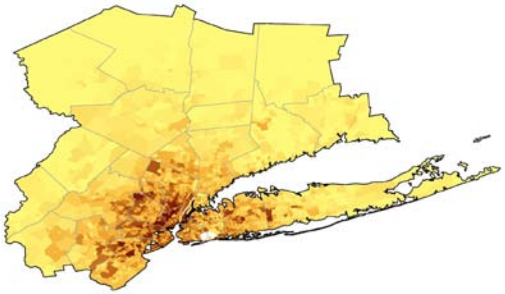
M6 [31.9 million tons]



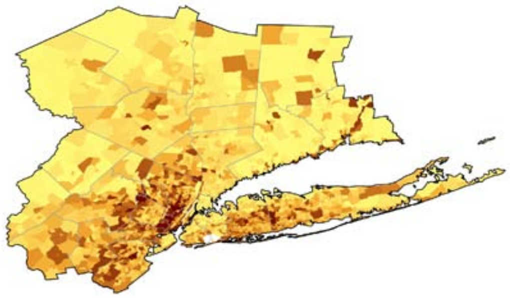
500-yr RETURN PERIOD [3.1 million tons]



M7 [132.1 million tons]

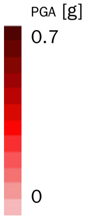


2500–yr RETURN PERIOD [34.0 million tons]



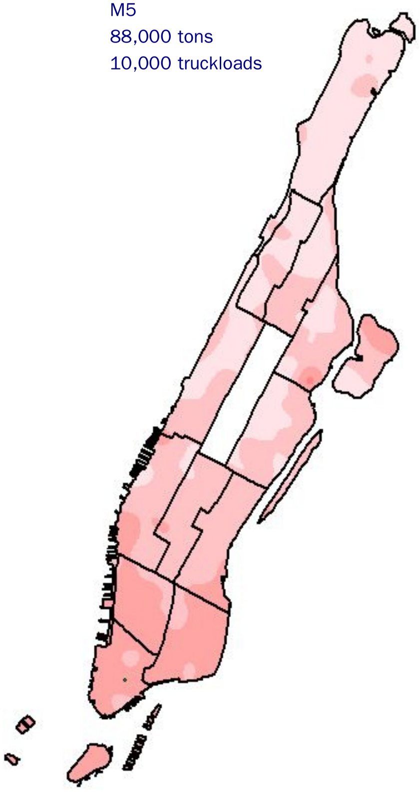
## DEBRIS (cont.)

***Even in a moderate M5 earthquake, there would be an estimated 88,000 tons of debris (10,000 truckloads), which is 136 times the garbage cleared in Manhattan on an average day.***



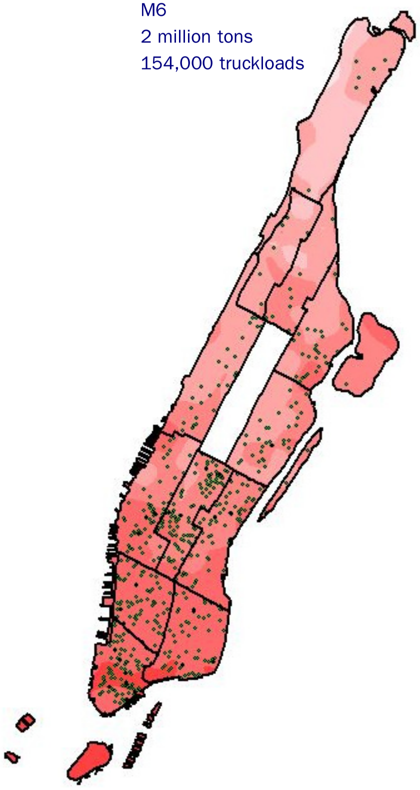
A dot in these figures indicates 10,000 tons of debris

M5
88,000 tons
10,000 truckloads



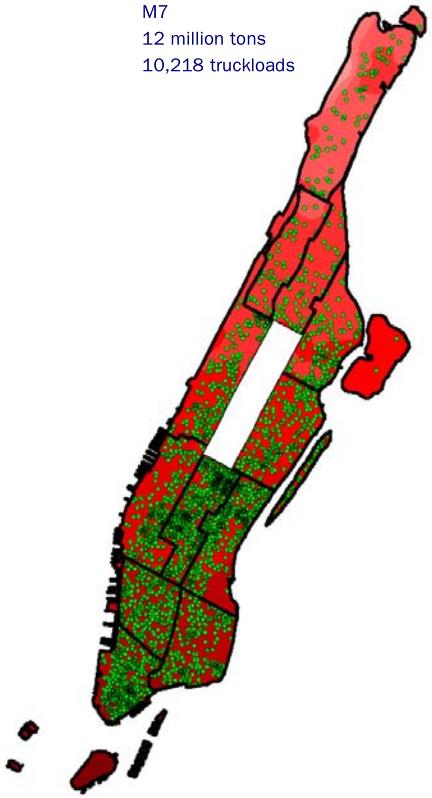
136x capacity of daily debris

M6
2 million tons
154,000 truckloads



9,200x capacity of daily debris

M7
12 million tons
10,218 truckloads



213,000x capacity of daily debris

# IMPLEMENTATION: WHAT IS BEING DONE?

***Credible estimates of future loss possibilities can be effective tools in encouraging area stakeholders to mitigate against the damaging consequences of earthquakes.***

An important objective of this study is to convey that a low-probability event is a potential reality, carrying with it consequences for which the metropolitan area may be ill prepared. To this end, numerous outreach activities have been initiated for:

- Creating awareness
- Putting building and soil inventory data into practice
- Verifying and improving the *HAZUS* loss estimation methodology, and
- Mitigating risks and minimizing losses

## Creating Awareness

As part of this outreach, a consortium was formed – the *New York City Area Consortium for Earthquake Loss Mitigation* (NYCEM). The Consortium is an umbrella group of interested organizations and major public and private stakeholders from such areas as emergency management, public service, engineering, architecture, financial services, insurance, and academia. As active participants in the program, the members continue to work to mobilize their contributions of data and information about area building stock, supporting infrastructures, and socioeconomic systems. We are creating awareness of the potential hazards in several ways:

*Publications and website*

- Articles in local, regional, and national publications, including the *New York Times* (Dunlop 2002)
- *MCEER Bulletin*, which regularly reports NYCEM results
- NYCEM's website (http://www.nycem.org), a repository for technical reports, project results, research data, and maps generated by NYCEM

*Presentations, conferences, and meetings*

- Workshops and briefings to share information and refine the default data in *HAZUS*
- Papers and slide presentations at technical conferences, for key government agencies, and for emergency management groups
- Meetings and dialogues with emergency managers and regional stakeholders about the importance of earthquake hazard mitigation

*Media activities*

- TV program on The Discovery Channel called, "Earthquakes in New York?"
- TV focus piece on WNBC-News

## Putting Research into Practice

An effective way to stimulate interest is by putting our research into practice. After the 9/11 World Trade Center terrorist attacks, for example, our comprehensive building inventories (1 million individual records) were used effectively for:

- Assessing and mapping building damage at Ground Zero, as well as estimating roof damage and debris, to assist the Structural Engineer's Association of New York (SEAoNY)

***We anticipate that the activities of the Consortium will stimulate broader community interest in joining this important effort.***

- Predicting losses from the 9/11 terrorist attacks several weeks after they happened, using the *HAZUS* loss estimation methodology

### Verifying and Improving *HAZUS*

Credible estimates of future loss can be effective tools in encouraging area stakeholders to mitigate against the possible future damaging consequence of earthquakes. Therefore, we are continuing to develop the necessary databases of geologic and building information to verify and improve the default database in *HAZUS*. These efforts include:

- Simulating real earthquakes (April 20, 2002 in Ausable Forks, NY) to verify the accuracy of loss estimates generated with *HAZUS* software

- Improving the analysis capability of *HAZUS* through continued research on New York's tall buildings, a "uniquely metropolitan" infrastructure that concentrates value and people

- Continuing to develop soil data and building inventories to refine the default data contained within *HAZUS*

### Mitigating Risks and Minimizing Losses

Some key implementation strategies for mitigating risk and minimizing losses have already been initiated. For example:

- Establishing a seismic building code for NYC (signed by Mayor Giuliani in 1995), initiated by the Seismic Code Committee (formed in 1989), and implemented by the Structural Engineers Association of New York (formed in 1996)

- Retrofitting vulnerable buildings and existing infrastructure

- Better regulating future construction by promoting seismic provisions in building codes

- Adding earthquake scenarios to emergency response plans before and after an earthquake, including plans for training and drills for employees

- Promoting legislation that encourages seismic risk reduction, including the use of tax incentives

- Increasing public awareness of the potential hazards

We anticipate that the activities of the Consortium will stimulate broader community interest in joining this important effort.

***The results suggest that HAZUS did well in its estimates and that there is good agreement between actual losses and predicted consequences.***

### Putting *HAZUS* to the Test

How well does *HAZUS* predict loss? The M5 earthquake at Ausable Forks in Upstate New York, on April 20, 2002, provided an opportunity to compare actual losses in the region with *HAZUS* predictions. A preliminary validation of the *HAZUS* model was conducted by the New York State Emergency Management Office (SEMO), using the Ausable Forks earthquake as a test case. First, we input earthquake scenario data in *HAZUS*, mirroring the Ausable Forks event.[1] Then we compared the "direct economic losses to buildings" sustained from this event with *HAZUS*-estimated losses.

### Actual Losses

Actual losses from the Ausable Forks earthquake, including damage to lifelines, were in excess of $8 million. Of this figure, approximately $5.85 million were attributed to structural and non-structural building elements. This estimate includes $3.85 million to residential structures[2] and $2 million to non-residential structures.[3] Most of the damage was to building foundations and chimneys. Very little damage to building "contents" was reported.

### Predicted Losses

Simulating the same earthquake, *HAZUS* predicted that the structural and non-structural losses for this event would be $4.53 million, just $1.32 million less than the $5.85 million estimated actual damage. This is a generally acceptable level of error; in fact, it may have been even less if more detailed soil maps had been used. Additionally, *HAZUS* estimated that there would be $3.8 million in "contents" losses and $32,000 in inventory loss. In actuality, very little "contents" damage was reported; however, if a comparable earthquake had occurred downstate in the New York City metro area, then the predicted "contents" losses might apply.

### How Well Does *HAZUS* Predict Loss?

The results suggest that *HAZUS* did well in its estimates and that there is good agreement between actual losses and predicted consequences.

---

[1] 5.0 Mw; depth 11Km; Project 97East Coast attenuation function; soil type B used over the entire six-county study region (Essex, Clinton, Warren, Franklin, Hamilton, Washington).

[2] Derived from FEMA's "Individual Assistance" (IA) disaster assistance program, which paid out $2.85 million in grant monies, as of July 2002, to repair residences. In addition to accounting for individuals not applying for assistance and non-discovery of damages, an additional $1 million was factored to the IA grant monies to arrive at the figure of $3.85 million in damages to residential structures.

[3] As the "Public Assistance" category of disaster aid was not included in the Presidential Disaster Declaration for the Ausable Forks earthquake (FEMA-1415-DR-NY), comprehensive damage figures on publicly owned buildings were not documented through a disaster assistance process. A rough damage estimate of $2 million for publicly owned and other non-residential structures was collected during the damage assessment.

# ESTIMATING DAMAGE: WTC APPLICATION

After the 9/11 World Center terrorist attacks, NYCEM's comprehensive building inventory data proved extremely useful to the Structural Engineer's Association of New York (SEAoNY) to assess and map the following:

### Building Damage at Ground Zero

Using a local subset of the 1 million individual building records from our database, complemented with other information available from FEMA, the SEAoNY engineers were better able to estimate the overall building conditions after the WTC attack, including the damage to surrounding buildings at Ground Zero. The color-coded findings are shown on the map to the right.

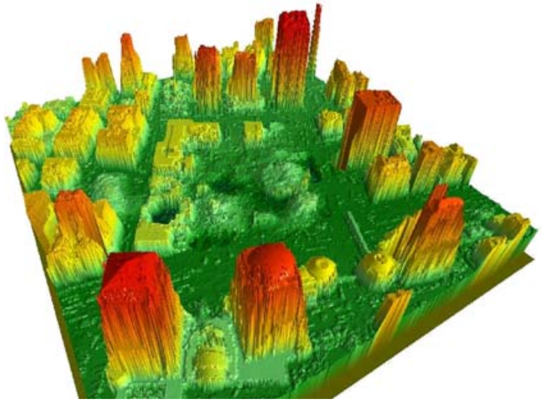
### Financial Losses

Using data obtained from our HAZUS methodology, with some modifications and engineering judgment, we were also able to provide FEMA with cost estimates of the financial losses from the attack – right after they happened.

### Roof Damage and Debris

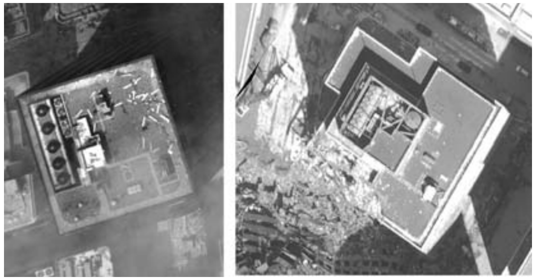
Using aerial photography and light detection and ranging (LIDAR) 3-D point data provided by the National Oceanic and Atmospheric Administration (NOAA), SEAoNY engineers were also able to estimate roof damage and debris, which is not easily determined on foot. With the benefit of geographic information systems (GIS) and data made available by this study, SEAoNY was able to make a more detailed assessment of the scope of destruction at and near the World Trade Center site.

These applications suggest the potential use of the NYCEM database to assess and mitigate other risks and hazards, including damage from terrorist attacks, in the NY-NJ-CT region of study.



These figures show how NYCEM project data was used with aerial photography and 3D point data to estimate overall building conditions, roof damage, and debris. This information is not easily determined on foot without GIS or data that was available to this group.

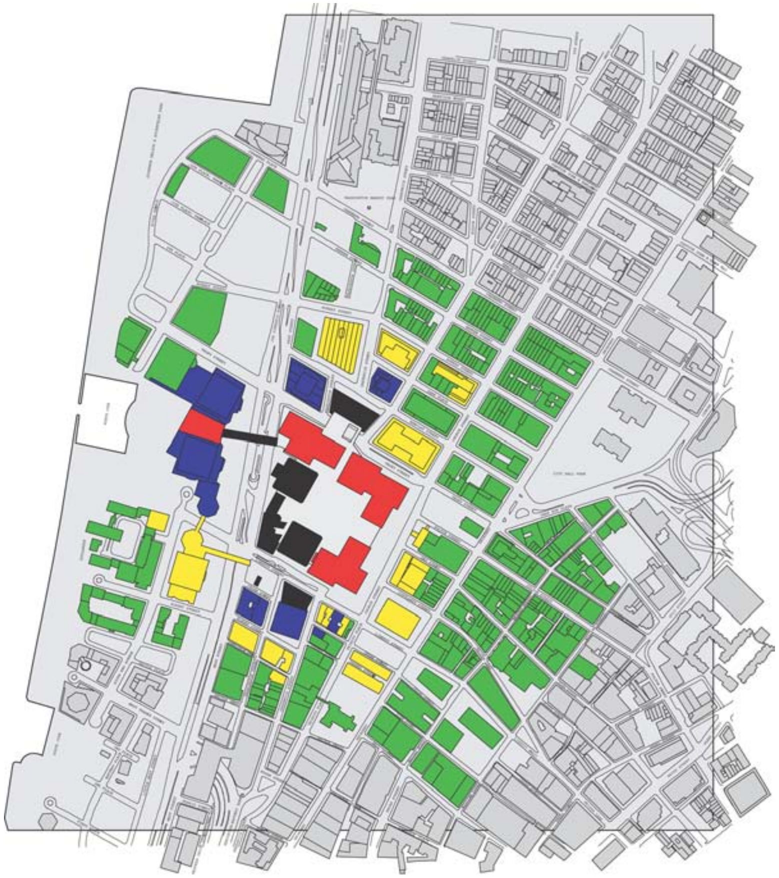
Source: NOAA LIDAR



Source: NYS Office for Technology

BUILDING CLASSIFICATIONS

- 🟩 no damage
- 🟨 moderate damage
- 🟦 major damage
- 🟥 partial collapse
- ⬛ complete collapse



SEAoNY with NYCEM, World Trade Center Building Performance Study, Preliminary Observations and Recommendations, FEMA, Region II, 2002.

## FUTURE WORK: WHAT STILL NEEDS TO BE DONE?

### *With accurate regional data, the modeling of risks from any hazard can be extended beyond earthquakes to improve our understanding of the potential impacts of these perils, providing a framework for building an all-hazard, disaster-resilient metropolitan area.*

Although the building inventories and soil data developed in this study are invaluable for future regional studies, further involvement by emergency responders, planners, builders, and health and human services officials will help improve the effectiveness of this study. We recommend future work in the following key areas:

### Earthquake Mitigation

The NYCEM team will continue to update building and soil information, refining and verifying the default database within *HAZUS*, as a tool for assisting area planners, responders, and other stakeholders. Additional data collection and study of regional lifeline systems (water, gas, sewerage, waste-water treatment, highway, and public transportation systems) will significantly enhance the risk characterizations that *HAZUS* can provide for the New York City area. Metropolitan transportation engineers are interested in being a part of possible future studies that would include transportation lifelines in the model. Additional and more accurate data, enabled by widespread participation by current and new stakeholders, will lead to the development of a better model to be embraced by responders, builders, and the public.

### Multiple Hazards Mitigation

Historically, the NY-NJ-CT region has experienced many of the deadly forces of nature – hurricanes, floods, tornadoes, blizzards, and earthquakes – many already costing over $200 million per event, and the region continues to be at risk from man-made threats. With accurate regional data, the loss estimation methodology can be extended to include these and other hazards (e.g., terrorist attacks) to improve the disaster resiliency of the metropolitan area. In the near term, this research may be extended using the recently released *HAZUS*-MH (which provides loss estimations for earthquakes, hurricanes, and floods) to include all three hazards, and to expand the scope of the study to include lifelines, highways, bridges, subways, harbors, airports and other infrastructure. The figures on the next page illustrate risk concentration for a variety of hazards.

### Emergency Response and Relief

Emergency response and relief agencies may use this study to project the demand on critical facilities (schools, hospitals, police, fire stations), as well as the financial and material resources required to assist victims. This could involve allocating limited funding for fire station or hospital retrofit. In addition, search and rescue operations may benefit from training in simulated situations and scenarios. By looking ahead, not only will we be able to identify areas, structures, and systems at highest risk and improve our understanding of the problem, but also our understanding of the *number of lives* and *value at risk*.

### Facts About Hazards

▸ In the past quarter century alone, there have been more than 100 federally declared disasters in the Northeast, or on average, about 4 major disasters per year.

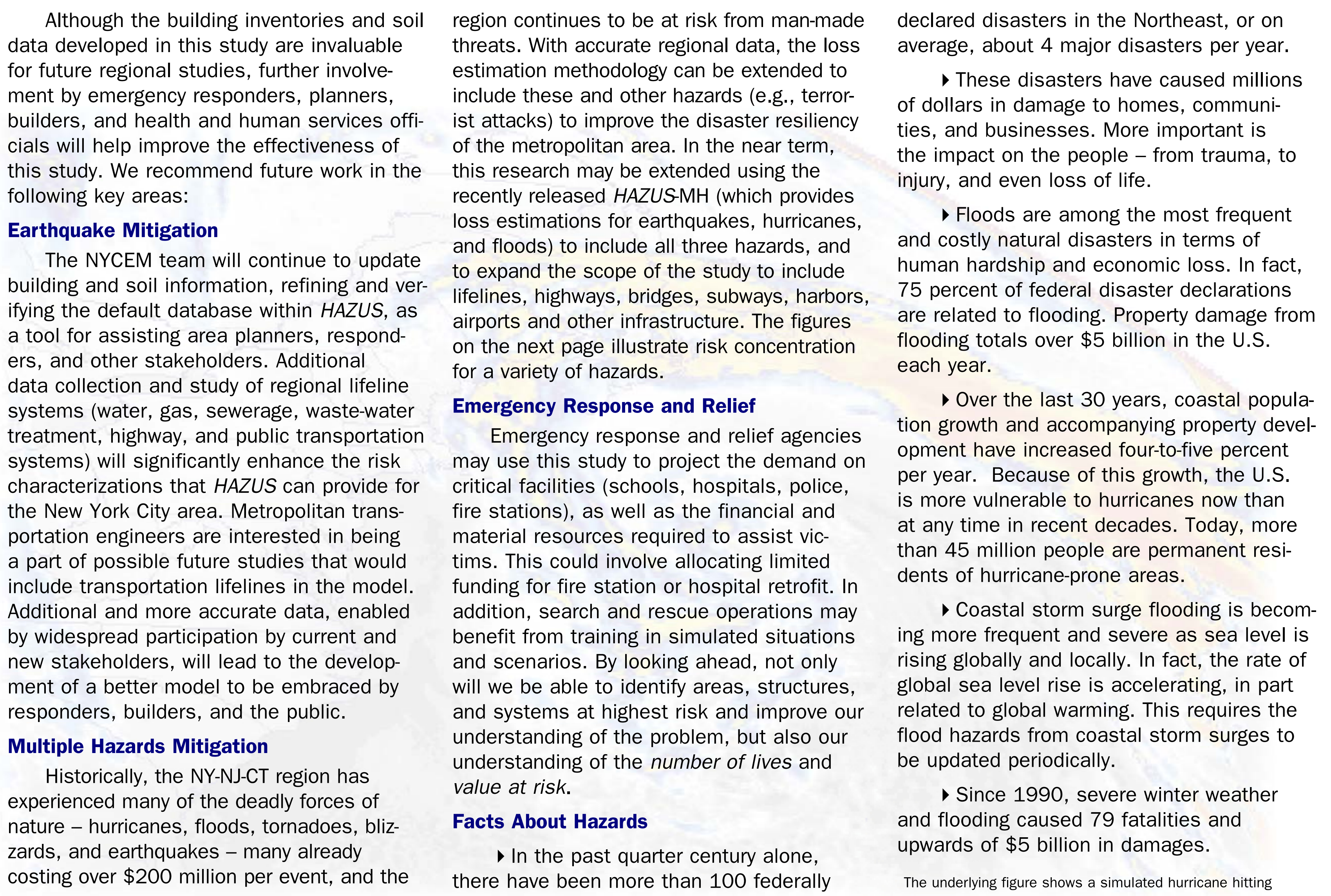
▸ These disasters have caused millions of dollars in damage to homes, communities, and businesses. More important is the impact on the people – from trauma, to injury, and even loss of life.

▸ Floods are among the most frequent and costly natural disasters in terms of human hardship and economic loss. In fact, 75 percent of federal disaster declarations are related to flooding. Property damage from flooding totals over $5 billion in the U.S. each year.

▸ Over the last 30 years, coastal population growth and accompanying property development have increased four-to-five percent per year. Because of this growth, the U.S. is more vulnerable to hurricanes now than at any time in recent decades. Today, more than 45 million people are permanent residents of hurricane-prone areas.

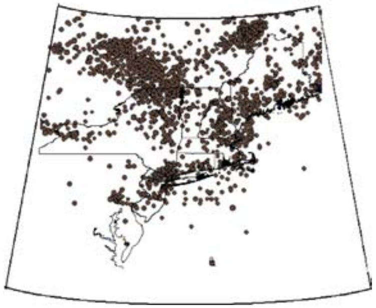
▸ Coastal storm surge flooding is becoming more frequent and severe as sea level is rising globally and locally. In fact, the rate of global sea level rise is accelerating, in part related to global warming. This requires the flood hazards from coastal storm surges to be updated periodically.

▸ Since 1990, severe winter weather and flooding caused 79 fatalities and upwards of $5 billion in damages.

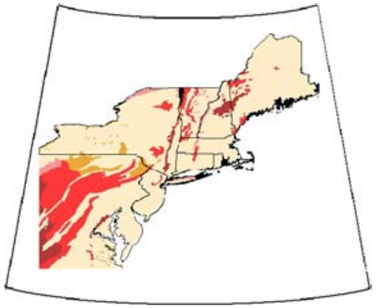


The underlying figure shows a simulated hurricane hitting the northeast.

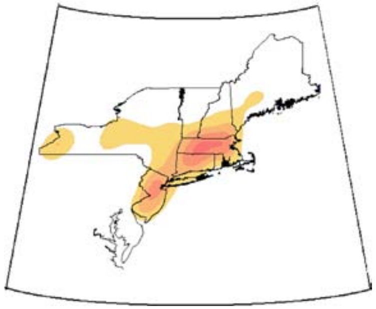
# AN ANATOMY OF REGIONAL RISKS

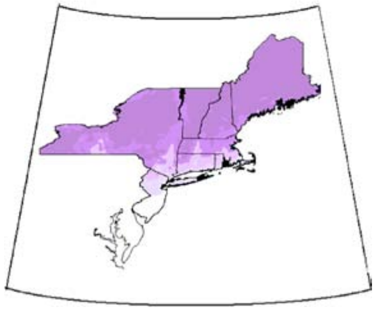

HISTORICAL EARTHQUAKE EPICENTERS

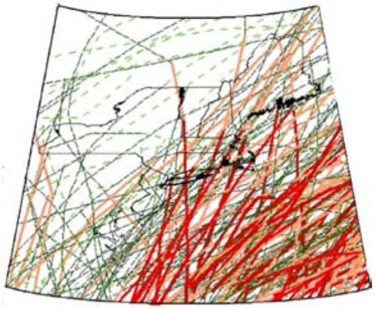

EARTHQUAKE HAZARD

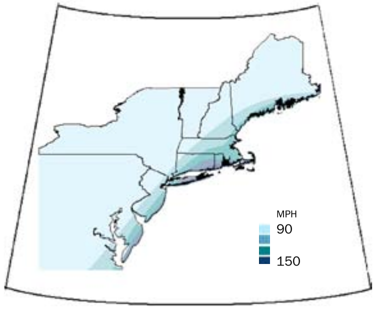

LANDSLIDE SUSCEPTIBILITY

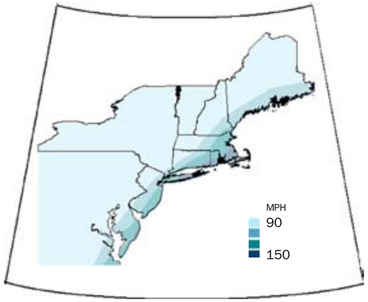

HISTORICAL TORNADOES


TORNADO DENSITY


AVERAGE ANNUAL SNOWFALL


HISTORICAL HURRICANE PATHS


100-yr WIND EXPOSURE


500-yr WIND EXPOSURE

The figures show the historical events and risk concentration for a variety of hazards, including earthquakes, landslides, tornadoes, snow storms, and hurricanes. Darker regions indicate greater susceptibility to hazard. A robust disaster management program would consider the risks and consequences of these events occurring in tandem over time.

# GLOSSARY

ACCELERATION – Rate of change of velocity with time, exerting a force on any mass or structure. When you step on the accelerator in the car or put on the brakes, the car goes faster or slower. When it is changing from one speed to another, it is accelerating (faster) or decelerating (slower). This change from one speed, or velocity, to another is called acceleration. During an earthquake when the ground is shaking, it also experiences acceleration. The peak acceleration is the largest acceleration recorded by a particular station during an earthquake

ACCELEROGRAM – A recording of the acceleration of the ground during an earthquake

AMPLIFICATION – A relative increase in ground motion between one type of soil and another or an increase in building response as a result of resonance

ATTENUATION – The rate with which ground motion shaking amplitude diminishes with distance for an earthquake with given magnitude. Ground motions attenuate more rapidly with distance in the western US, and more slowly in the central and eastern US.

DESIGN EARTHQUAKE – (In US recommended building codes) The earthquake that produces ground motions at the site under consideration that has a 98 percent probability of not being exceeded in 50 years (or a 2 percent probability of being exceeded)

EARTHQUAKE – A sudden motion or vibration in the earth caused by the abrupt release of energy in the earth's lithosphere

EPICENTER – A point on the earth's surface that is directly above the focus of an earthquake

EXCEEDANCE probability or probability of exceedance – The probability that specified level of ground motion or specified social or economic consequences of earthquakes will be exceeded at a site or in a region during a specified exposure time

"g" – the acceleration due to gravity or 32 feet per second per second

INTENSITY – The intensity is a number (written as a Roman numeral) describing the severity of an earthquake in terms of its effects on the earth's surface and on humans and their structures. Several scales exist, but the one most commonly used in the United States is the Modified Mercalli scale. There are many intensities for an earthquake, depending on where you are, unlike the magnitude, which is one number for each earthquake

MAGNITUDE – A number that characterizes the relative size of an earthquake. Magnitude is based on measurement of the maximum motion recorded by a seismograph. Several scales have been defined, but the most commonly used are (1) local magnitude (ML), commonly referred to as "Richter magnitude," (2) surface-wave magnitude (Ms), (3) body-wave magnitude (Mb), and (4) moment magnitude (Mw). This study uses the moment magnitude scale.

MOMENT MAGNITUDE (Mw) – A scale based on the concept of seismic moment, is uniformly applicable to all sizes of earthquakes but is more difficult to compute than the other types. All magnitude scales yield similar but not identical values for any given earthquake.

PERIOD – The period is the time interval required for one full cycle of a wave

RECURRENCE INTERVAL – The recurrence interval, or return period, is the average time span between large earthquakes at a particular site.

RICHTER SCALE – The Richter magnitude scale was developed in 1935 by Charles F. Richter of the California Institute of Technology as a mathematical device to compare the size of earthquakes. The magnitude of an earthquake is determined from the logarithm of the amplitude of waves recorded by seismographs. Adjustments are included for the variation in the distance between the various seismographs and the epicenter of the earthquakes. On the Richter Scale, magnitude is expressed in whole numbers and decimal fractions. For example, a magnitude 5.3 might be computed for a moderate earthquake, and a strong earthquake might be rated as magnitude 6.3. Because of the logarithmic basis of the scale, each whole number increase in magnitude represents a tenfold increase in measured amplitude; as an estimate of energy, each whole number step in the magnitude scale corresponds to the release of about 31 times more energy than the amount associated with the preceding whole number value.

EARTHQUAKE HAZARD – Earthquake hazard is anything associated with an earthquake that may affect the normal activities of people. This includes surface faulting, ground shaking, landslides, liquefaction, tectonic deformation, tsunamis, and seiches.

EARTHQUAKE RISK – Earthquake risk is the probable building damage, and number of people that are expected to be hurt or killed if a likely earthquake on a particular fault occurs. Earthquake risk and earthquake hazard are occasionally incorrectly used interchangeably.

SEISMIC HAZARD ASSESSMENT – It exists fundamentally in two forms: Probabilistic and Deterministic Assessments:

DETERMINISTIC SEISMIC HAZARD ASSESSMENT – The quantitative specification of seismic hazards, most commonly expressed as a level of ground motion shaking at a given site, or for an entire region (in map form), for a given scenario earthquake, or a sequence of scenario events. One must specify the magnitude(s) and location(s) of the scenario earthquakes regardless of how likely their occurrence and time horizon is. Also, all the uncertainties are generally not considered rigorously.

PROBABILISTIC SEISMIC HAZARD ASSESSMENT – A rigorous method that quantitatively combines information and all of its uncertainties about seismicity (including the entire range of earthquake magnitudes and locations that can contribute to damage), ground motion attenuation, and site location for which the assessment is made. The result is most commonly expressed in terms of a probability of reaching or exceeding a given level of ground shaking per unit time. For example, the assessed peak ground acceleration at the evaluated site may be expected to be reached or exceeded with a 2% probability in a 50-year exposure time, implying a 98% probability in 50 years NOT to be exceeded. This is equivalent to saying that this level of ground motion can be expected or exceeded on average once every 2,475 years; or has an annual probability of 1/2,475 = 0.04% per year. If the evaluation is done for an entire region rather than for a single site, the result is usually displayed in form of a probabilistic seismic ground shaking hazard map.

SEISMICITY – Seismicity refers to the geographic and historical distribution of earthquakes and of their magnitudes.

SOIL PROFILE – The soil profile is the vertical arrangement of layers of soil down to the bedrock.

SOIL – Soil is (1) In engineering, all unconsolidated material above bedrock. (2) In soil science, naturally occurring layers of mineral and (or) organic constituents that differ from the underlying parent material in their physical, chemical, mineralogical, and morphological character because of pedogenic processes.

SOURCE – The source is the term for the released forces that generate acoustic or seismic waves, also called the earthquake source

VELOCITY – Velocity is how fast a point on the ground is shaking as a result of an earthquake.

VULNERABILITY – The degree of loss to a given element at risk, or set of such elements, resulting from an earthquake of a given intensity or magnitude; expressed in a scale ranging from no damage to total loss; a measure of the probability of damage to a structure or a number of structures

# REFERENCES AND RELATED PUBLICATIONS

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