Appendix E
CASUALTY ESTIMATION METHODOLOGY

E.1 Earthquake – Structural Mitigation Projects

The most developed component of HAZUS is the earthquake module, which was used on this project to determine the benefits of Structural Mitigation projects (e.g., retrofitting a building to improve the earthquake resisting properties of its structural framing system). The benefit of mitigation, expressed in terms of reduced casualties, is the difference between the number of casualties for the structure in its unmitigated state, and the number of casualties for the structure in its mitigated (e.g., retrofitted) state. HAZUS bases its casualty methodology primarily on structural and nonstructural damage. The methodology does not consider casualties due to secondary sources such as power outage or car accidents. The methodology uses casualty rates predominantly based on ATC-13 (Applied Technology Council, 1985), but updated through historical data. (ATC-13 documents an earthquake loss-estimation methodology and provides extensive damage-evaluation data for California). The HAZUS methodology for estimating casualties from structural damage combines a variety of inputs from other HAZUS modules including the probability of being in the damaged state and the relationship between the general occupancy classes and the model building type with specific casualty inputs in combination with occupancy data and time of event. Table E-l highlights the inputs needed for the HAZUS earthquake casualty estimates.

The output from HAZUS reports casualties based upon magnitude of modeled event, day or night scenario, and estimated injury classification. Injury classification focuses on the severity of the estimated injury.

Table E-1 Input variables for HAZUS casualty module in relation to damage state

Variable	Slight	Moderate	Extreme	Complete		Comments
1. Occupancy						
a. 2 p.m.	Same	Same	Same	Same		Day Occupancy
b. 2 a.m.	Same	Same	Same	Same		Night Occupancy
2. Indoor Casualty Rates				*No Collapse*	*Collapse*	Default based on building type
a. Severity 1	.05	.25	1	5	40	
b. Severity 2	0	.030	.1	1	20	
c. Severity 3	0	0	.001	.01	5	
d. Severity 4	0	0	.001	.01	10	
3. Collapse Rate	n.a.	n.a.	n.a.	10%		Default based on building type
4. Probability of Building being in Damage State	Default	Default	Default	Default		Input from other HAZUS Modules

Severity 1 injuries are the least life threatening, but may require basic medical aid from paraprofessionals such as paramedics. Severity 2 injuries require more medical care and the use of medical technology such as x-ray. These types of injuries are not expected to be life threatening. Severity 3 injuries pose an immediate life threatening condition if not treated quickly and thoroughly. Severity 4 injuries instantly kill or mortally injure (see HAZUS Technical Report, Table 13.1)

Translating injuries and loss of life into quantifiable dollar figures is difficult. Estimates of the value of life vary greatly – from $1 to $10M depending on the agency and use of the figure (Porter, 2002). One of the most applicable figures is from a 1998 study for the Federal Aviation Administration by Hoffer et al. (1998), who estimate the value of a human life at $3M. The methodology uses the $3M figure as its estimate for loss of life.

The development of injury costs for each HAZUS level used Federal Highway Administration data. The least serious injury is valued at $17,000 while the most extreme, loss of life, uses the $3 million FAA estimate discussed above. These values are used for all hazards.

E.2 Earthquake — Nonstructural Mitigation Projects

HAZUS is unable to model the benefit of nonstructural mitigation (projects that result in reduced casualties as a result of reduced damage to nonstructural components, such as ceilings and light fixtures) as it relates to deaths and injuries. For this project, three broad types of nonstructural mitigation were most prevalent: pendant lighting retrofit in schools, ceiling retrofit, and various types of bracing. A literature search revealed that little data exist to help model the reduction of injuries and deaths from these three types of nonstructural mitigation projects. Most available studies examine injuries that occur from other kinds of nonstructural damage. This is because no major earthquake has occurred during school and work hours. Following the 1994 Northridge Earthquake it was reported that "The Northridge Earthquake caused hundreds of lighting units to fall onto desks in classrooms that the students and teachers would normally occupy during a school day. Fortunately, the earthquake occurred early in the morning when the schools were closed in observance of Dr. Martin Luther King, Jr. Day (FEMA, 2004)". Such information highlights the issue, but does not provide enough data to estimate the probability either that lights will fall or that falling lights will injury people.

This project conservatively estimates the benefits of this type of mitigation. Assumptions are based on engineering judgment developed and reviewed by individuals with considerable experience in earthquake engineering and mitigation.

Seligson et al. (1998) suggest that without mitigation, pendant lighting in areas with high shaking likelihood has a moderate probability of falling, and with mitigation, a low probability of falling. The authors do not estimate numeric savings, but the methodology used here focuses on "low probability" of falling as a general guideline.

The project team estimated that without mitigation, between 1% and 10% of pendant lights will fall in earthquakes some time during the life of the building (assumed to be 50 years). A best-estimate value of 5% is used. Next, the method assumes that mitigation reduces the potential for collapse by half. Thus, 2.5% of the lights would have fallen during the next 50 years but will not fall after mitigation. Therefore, if a mitigation project replaces 1,000 pendant lights, 25 lights that would have fallen in an earthquake prior to mitigation now will not fall.

A second assumption relates to how many of those 2.5% (or in the above example, 25) would injure a person. The project team considered a variety of issues that would influence whether someone was injured from a falling pendant light including: (1) likelihood of a light falling where someone was standing or sitting immediately before the earthquake and (2) the likelihood that an individual would either not take protective action or that that action would be inadequate to protect him or her from being hit by the falling debris.

While empirical data are unavailable about these important likelihoods, it is asserted that: (1) the likelihood of a light falling on someone depends on how desks and classrooms are set up (when projects mitigate lights in schools) or where people are located spatially within a room or building; and (2) in areas with high earthquake risk, people are taught to take protective measures when they first become aware of ground shaking. In schools, children receive specific education to go under their desks, and as with fire, they routinely participate in earthquake drills. For purposes of this project, pendant lights are assumed to be approximately 6 inches wide, spaced approximately 6 ft apart, and typically almost the length of the room, meaning they hang over approximately 8% of the floor area. It is also assumed that a falling light could harm someone standing beneath or within 9 inches on either side of the light, thus affecting approximately 33% of the floor area, and therefore impacting 33% of unprotected occupants. Since schools are occupied approximately 25% of the time, it is assumed that approximately 0.33 x 0.25 or 8% of unprotected occupants would be injured if a light fell on them. Further assuming a 50-50 chance that an occupant would effectively protect him- or herself, 4% of the lights that would fall are judged to hit someone and, thus, could cause a major injury in the context of HAZUS.

A similar methodology was used for ceiling retrofit and upgrade. In this case, it was assumed that 2.5% of the retrofitted area would have fallen if the retrofit had not occurred and that, for every 300 square feet of area (area assumed to be occupied by one person) that would not have fallen, an injury would be avoided. Therefore, if a project mitigated 100,000 square feet of ceiling, 2,500 square feet that may have fallen without mitigation will not fall with the mitigation, and of that 2,500 square feet, 8.3 injuries will be avoided (2,500 divided by 300). For mitigation of hard ceilings, the assumption is a reduction of a moderate HAZUS 2 injury, and for hanging ceilings which tend to be a lighter material, the assumption is a reduction of a minor HAZUS 1 injury.

While these estimates appear reasonable, caution must be used when considering them. The estimates are based on assumptions developed using engineering judgment, but are not grounded in empirical evidence. They should not be considered as exact empirically driven estimates, but rather, as best estimates considering available data and sound engineering judgment.

E.3 Flood Mitigation Projects

The majority of flood mitigation projects recorded in NEMIS are buy-outs of repeatedly flooded properties that HAZUS cannot model. To quantify social benefits, a method was developed that considers the number of units bought as part of each project. The method uses data on a variety of flood events that was published by the Center for Disease Control in *Morbidity and Mortality Weekly*. The challenge was to find reports that used households as the unit of analysis and, thus, could be applied to the current project.

Reports were examined on the Midwest Floods in 1993 (CDC MMWR Weekly, October 22, 1993), a 1994 flooding event in Georgia (CDC MMWR Weekly June 29, 1994), and Tropical Storm Allison in Houston (CDC MMWR Weekly May 3, 2002). The first two studies examined the deaths and injuries reported by hospitals and medical examiners while the third study examined injuries within households. The main hazard that resulted from Tropical Storm Allison was flooding. A cluster sample of housing units in selected census tracts was surveyed. Instead of relying on medical examiners or hospital reports, this assessment of injuries relied on self-reports from households.

The Tropical Storm Allison methodology is the most applicable to the current project since it uses housing units as the unit of analysis. While flood intensities do vary, we can already assume that the properties have a high likelihood of being flooded considering their inclusion in the buy-out program.

The Tropical Storm Allison study indicated that 8% of survey respondents reported that at least one person in their household experienced a flood-related injury. Flood related injuries include falls, blunt injuries, animal bites, and cuts or puncture wounds.

One of the major limitations of this method is that it focuses on one flooding event. As a result, the method uses one-half of the injury rate reported in the Allison study (4%) as the rate of injury for the properties purchased. Sensitivity studies used 2% and 8% as the lower and upper bound.

E.4 Wind Mitigation Projects – Hurricane

The majority of hurricane wind projects involved installing or upgrading hurricane shutters on a variety of public buildings such as city halls or hospitals. Because there is a warning period before hurricane landfall, most public buildings have little if any occupancy during a hurricane. The major exceptions are schools that act as hurricane shelters and hospitals that cannot evacuate all patients. Developing a methodology to estimate the social benefits of shutter mitigation was challenging. As a result, the method focuses on only those buildings used as shelters. Two hospital projects in the sample are not included because little empirical evidence supports the development of an appropriate method.

Similar to the flood methodology, the hurricane shutter methodology is based on three Center for Disease Control reports of injuries sustained in hurricane events. Injury estimates are conservative, and focus on injuries reported during hurricanes where evacuation orders were in place

The first report focuses on 1992's Hurricane Andrew in Louisiana (see CDC MMWR Weekly, April 9, 1993, 42:130). Findings indicate that the three parishes closest to the hurricane's track had injury rates over 200 per 100,000. Using these numbers, the hurricane injury rate is 0.2% for this storm.

In 1995, Hurricane Opal made landfall in the Florida Panhandle with sustained winds of 115 mph (Category III on the Saffir-Simpson Scale). A review of emergency department records for the six days before Hurricane Opal made landfall and the six days after Hurricane Opal made landfall shows no significant change in the number of visits for lacerations, wounds, sprains and fractures (CDC MMWR Weekly, February 2, 1986, 45:4).

A more recent CDC MMWR report focused on 2003's Hurricane Isabel, which made landfall on the Outer Banks of North Carolina. Using a cluster sample methodology, 210 interviews were completed (62.3% response rate). These 210 interviews represented 93,738 occupied housing units. Of the 210 interviews, only two households reported a hurricane related injury. Using these numbers, the hurricane injury rate is 0.9% for this storm.

Since these injury rates are case specific, the Project Team averaged the two rates to get a point estimate of 0.0055, and used .002 as the lower bound for a sensitivity study and .009 as the upper bound.

For each school shuttering project, the schools that were shuttered were divided into those that are used as shelters and those that are not designated as shelter . Based on the assumption that over the life of the project one hurricane will occur that will fill the shelter, shelter capacity information was retrieved from the State of Florida emergency management shelter status website (http://www.eoconline.org/EM_Live/shelter.nsf), and the proportions designated above were applied to represent quantified reduction in injuries. The majority of the shelter projects are in the State of Florida. Projects not in Florida are harder to model since required data, such as shelter capacity, are not readily available. The injuries avoided are moderate, HAZUS Level 2 injuries.

The assumption of one Andrew or Isabel-sized hurricane per 50 years is probably reasonable or modestly conservative. Hurricane Andrew's peak gusts were roughly 140 mph, approximately equal to 50-year design wind speeds, per NOAA. Hurricane Isabel's peak gust velocities were roughly 100 mph over a fairly wide region (NOAA, 2003). The 50-year design wind speeds there are approximately 130 mph, indicating that Isabel's wind speeds have an approximately 10-year recurrence period using Peterka and Shahid's wind speed-recurrence relationship (1998).

While the numbers appear conservative because they reflect evacuation, data from Hurricane Andrew supports the numbers. Hurricane Andrew had about 14 deaths (out of a population of 1.9M) directly due to the hurricane in an area that had limited evacuation. Using these numbers, the mortality rate would be approximately .000007368. This area had limited evacuation since evacuation is based on water (storm surge) and not wind. The area hardest hit by Hurricane Andrew was the southernmost locations such as Florida City, Homestead, and Kendall. These areas suffered significant damage, but were inland as compared to areas such as Miami Beach that were subject to evacuation orders. In fact, many people evacuated from low-lying areas to the area that was most devastated by the winds.

E.5 Wind Mitigation Projects – Tornado

The majority of tornado wind mitigation projects focus on construction or retrofit of saferooms in public spaces such as schools. HAZUS at present cannot model casualty estimates for tornadoes, so a probabilistic site-specific method of estimating the benefit of tornado saferooms was developed.

Using this methodology, the U.S. is first divided into 1 degree x 1 degree cells, and then, tornado touchdowns are counted. A baseline model is calculated to estimate annualized frequency at a site. This estimate uses models to determine response of structures to wind velocities and to estimate casualties per damage degree. The probabilities of occurrence are aggregated to different Fujita levels to correspond with 100 mile per hour and 200 mile per hour values.
The following table illustrates the injury rates used for the tornado estimation:

Table E-2 Injury rates used for tornado estimation

		Casualties per 1000 people**		
Degree of Damage	Damage State (percent damage)*	minor injuries	major injuries	deaths
minor	2%	0.1	0.01	0
moderate	10%	1.2	0.16	0.04
severe	50%	68.57	9.14	2.29
destruction	100%	400	400	200

* Repair cost divided by replacement cost
** Based on ATC-13 Injury and death rates

This methodology estimates the reduction in annualized casualties after mitigation, and the cost per injury type discussed above in the earthquake section, is applied to estimate dollar benefit of mitigation activities.