Benefit-Cost Analysis of FEMA Hazard Mitigation Grants

Adam Rose[1]; Keith Porter[2]; Nicole Dash[3]; Jawhar Bouabid[4]; Charles Huyck[5]; John Whitehead[6];
Douglass Shaw[7]; Ronald Eguchi[8]; Craig Taylor[9]; Thomas McLane[10]; L. Thomas Tobin[11];
Philip T. Ganderton[12]; David Godschalk[13]; Anne S. Kiremidjian[14]; Kathleen Tierney[15]; and
Carol Taylor West[16]

Abstract: Mitigation decreases the losses from natural hazards by reducing our vulnerability or by reducing the frequency and magnitude of causal factors. Reducing these losses brings many benefits, but every mitigation activity has a cost that must be considered in our world of limited resources. In principle, benefit-cost analysis (BCA) attempts to assess a mitigation activity's expected net benefits (discounted future benefits less discounted costs), but in practice this often proves difficult. This paper reports on a study that applied BCA methodologies to a statistical sample of the nearly 5,500 Federal Emergency Management Agency (FEMA) mitigation grants between 1993 and 2003 for earthquake, flood, and wind hazards. HAZUS MH was employed to assess the benefits, with and without FEMA mitigation in regions across the country, for a variety of hazards with different probabilities and severities. The results indicate that the overall benefit-cost ratio for FEMA mitigation grants is about 4:1, though the ratio varies from 1.5 for earthquake mitigation to 5.1 for flood mitigation. Sensitivity analysis was conducted and shows these estimates to be quite robust.

DOI: XXXX

CE Database subject headings: Benefit cost ratios; Hazards; Disasters; Federal agencies; Remedial action.

Introduction

Background

Mitigation decreases the losses from natural hazards by reducing our vulnerability or by reducing the frequency and magnitude of causal factors. Mitigation would ideally be implemented as extensively as possible, but, in a world of limited resources, its costs must be considered. Benefit-cost analysis (BCA) is a widely used tool to evaluate expenditures in this context (see, e.g., Zerbe and Dively 1994; FEMA 2005). If a mitigation activity's total expected benefits (avoided losses) exceed its total costs, and at a level comparable to both private and public investment rates of return, then it represents an efficient use of society's resources. A longstanding question has been: to what extent do hazard mitigation activities pass the BCA test?

Several programs authorize the use of federal funds to mitigate risks from natural hazards. Between mid-1993 and mid-2003, more than $3.5 billion of federal and state/local matching funds have been spent to reduce flood, windstorm, and earthquake risk. In light of those expenditures, the U.S. Congress directed the Federal Emergency Management Agency (FEMA) to fund an independent study to assess the future savings resulting from miti-

---

[1] Research Professor, School of Policy Planning and Development, Univ. of Southern California, RGL Room 230, Los Angeles, CA 90089-0626; formerly, Pennsylvania State Univ., University Park, PA 16802 (corresponding author). E-mail: adam.rose@usc.edu

[2] Dept. of Civil, Architectural, and Environmental, Univ. of Colorado, Boulder, CO 80309.

[3] Associate Professor, Dept. of Sociology, Univ. of North Texas, P.O. Box 311157, Denton, TX 76203.

[4] Technical Director, RMS, 415 Fox Chase Circle, Alpharetta, GA 30005.

[5] Vice President, ImageCat, Inc., Union Bank of California Building, 400 Oceangate, Suite 1050, Long Beach, CA 90802.

[6] Professor, Appalachian State Univ., Raley Hall, Boone NC 28608. E-mail: whiteheadjc@appstate.edu

[7] Professor, Agricultural Economics Dept., Texas A&M Univ., Mailstop 2124, College Station, TX 77843.

[8] President, ImageCat, Inc., Union Bank of California Bldg., 400 Oceangate, Suite 1050, Long Beach, CA 90802. E-mail: rte@imagecatinc.com

[9] President, Natural Hazards Management, Inc., Torrance, CA 90505.

[10] Director of Business Development, Applied Technology Council, 211 Wilson Boulevard, Suite 700, Arlington, VA 22201. E-mail: tmclane@atcouncil.org

[11] President, Tobin & Associates, 134 California Ave., Mill Valley, CA. E-mail: lttobin@aol.com

[12] Professor, Economics Dept. UNM, Univ. of New Mexico, MSC05 3060, Albuquerque , NM 87131. E-mail: gandini@unm.edu

[13] Professor Emeritus, Univ. of North Carolina at Chapel Hill, 204 New East, Chapel Hill, NC 27599. E-mail: dgod@email.unc.edu

[14] Professor, Dept. of Civil and Environmental Engineering, Stanford Univ., Terman Engineering Center, Room 238, Stanford, CA 94305-4020. E-mail: ask@stanford.edu

[15] Director, Univ. of Colorado, Natural Hazards Center, 327 UCB, Boulder, CO 80309. E-mail: tierneyk@colorado.edu

[16] Professor, Dept. of Economics, Univ. of Florida, P.O. Box 11745, Gainesville, FL 32611-7145.

Note. Discussion open until April 1, 2008. Separate discussions must be submitted for individual papers. To extend the closing date by one month, a written request must be filed with the ASCE Managing Editor. The manuscript for this paper was submitted for review and possible publication on January 31, 2006; approved on September 18, 2006. This paper is part of the ***Natural Hazards Review***, Vol. 8, No. 4, November 1, 2007. ©ASCE, ISSN 1527-6988/2007/4-1–XXXX/$25.00.

gation activities (U.S. Senate 1999). This paper summarizes the results of applying BCA to a nationwide statistical sample of FEMA-funded mitigation activities.

Overview

The results of the benefit-cost analysis of FEMA hazard mitigation grants are presented and explained below. These results are based on the data and methods summarized in MMC (2005, Chaps. 3 and 4). Results are presented for two major categories of grants—project activities and process activities; and for three hazards—earthquake, flood, and wind (hurricanes, tornados, and other windstorms), for a total of six strata. The results for a third category of grants, Project Impact grants, are presented in MMC (2005, Chap. 5). The grant programs analyzed in this paper represent 72% of all FEMA hazard mitigation grants and 80% of all associated FEMA expenditures during the study period. Specific methods and data used in the estimation of each stratum are also briefly summarized.

Because this was an analysis of overall mitigation savings, rather than a review of FEMA grant-making procedures, the objective was to estimate major statistical indicators applicable to an entire stratum: the mean benefit and its standard deviation. This involved estimating benefits from a sample of individual grants such as purchase and demolition of property in floodplains, and base isolation of seismically vulnerable buildings, and then extrapolating results to the population of grants by a mathematical process detailed later.

Overall, the benefit-cost analysis of FEMA hazard mitigation grants found that the benefit-cost ratio (BCR) of each stratum was greater than 1.0. Moreover, this result is robust to formal sensitivity tests (tornado-diagram analyses, discussed later) and informal evaluations of methodological limitations and assumptions (discussed throughout the present paper). The total national benefits of FEMA hazard mitigation grants between mid-1993 and mid-2003, in terms of avoided future losses during the useful life of these mitigation efforts (which varies by grant) are estimated to be $14.0 billion in year 2004 constant dollars, compared with $3.5 billion in costs. This yielded an overall BCR of 4.0. Thus, every dollar spent on a FEMA hazard mitigation grant produced, on average, four dollars of benefits—a significant return on public dollar expenditures, comparable to a 14% rate of return on a 50-year annuity.

Methodology

The benefits of hazard mitigation are the avoided losses, i.e., those losses that would have occurred (in a probabilistic sense) if the mitigation activity had not been implemented. It is important at the outset to note two key differences between mitigation costs and benefits. Mitigation costs are incurred primarily during a short period, such as during construction, and are relatively certain. The only exception pertains to operating costs and maintenance costs, but these are usually relatively minor in comparison to construction costs. Mitigation benefits, however, accrue over the useful life of the project or process activity and are highly uncertain because they are usually realized only if natural hazard events occur. At best, the expected value of benefits of mitigation measures currently in place can only be approximated by multiplying the potential total benefits of an event of various sizes by the probability of each event, and summing over all such events. In addition, benefits must be discounted to present value terms to account for the time value of money (see, e.g., Rose 2004b; Ganderton 2005).

The various categories of hazard mitigation benefits addressed in this paper are as follows:

1. Reduced direct property damage (e.g., buildings, contents, bridges, pipelines);
2. Reduced direct business interruption loss (e.g., factory shutdown from direct damage or lifeline interruption);
3. Reduced indirect business interruption loss (e.g., ordinary economic “ripple” effects);
4. Reduced (nonmarket) environmental damage (e.g., wetlands, parks, wildlife);
5. Reduced other nonmarket damage (e.g., historic sites);
6. Reduced societal losses (deaths, injuries, and homelessness); and
7. Reduced emergency response (e.g., ambulance service, fire protection).

Compared to benefit-cost analysis, loss estimation modeling is relatively new, especially with respect to natural hazard assessment. Although early studies can be traced back to the 1960s, only in the 1990s did loss estimation methodologies become widely used. A major factor in this development was the emergence of geographic information systems (GIS) technology that allowed users of information technology to easily overlay hazard data or information onto maps of urban systems (e.g., lifeline routes, building data, population information).

Loss estimation methodologies are now vital parts of many hazard mitigation studies. FEMA has recognized the value of loss estimation modeling as a key hazard mitigation tool. In 1992, FEMA began a major effort (which continues today) to develop standardized loss estimation models that could be used by nontechnical hazard specialists. The resulting tool, a software program called Hazards US-Multihazard (HAZUS MH), currently addresses earthquake, flood, and hurricane winds. HAZUS MH was extensively used in this study. A summary of HAZUS MH is presented in Appendix I, and more details of its application are presented during the course of the discussion below.

Not all benefits of mitigation evaluated in this study can be analyzed using traditional evaluation methods. Alternative approaches for assessing some categories of mitigation benefits were needed. For environmental and historic benefits, a feasible approach for measuring the benefits of hazard mitigation is the *benefit transfer* approach (see, e.g., Brookshire and Neil 1992; Bergstrom and DeCivita 1999). Valuation of environmental damages, cultural and historical damages, and lives is conducted by converting these “nonmarket” damages into dollars with the willingness to pay paradigm. The benefit of a policy is thus the amount of money, over and above expenditures or impacts, that members of society are willing to pay to obtain an increment in wellbeing or avoid a decrement in wellbeing. Willingness to pay is the theoretically correct measure of the economic benefits of a policy or project. Nonmarket valuation methodologies convert the intrinsic value of a nonmarket good into dollar values that can be added up and directly compared to policy costs. When the cost of primary data collection is prohibitive, as in this study, the benefit transfer approach is invoked, adapting previous estimates of willingness to pay.

Several assumptions underlie the analysis. Here we note the major ones and refer the reader to Appendix II for others. The base case real discount rate used is 2%, which is based on market interest rates. It is also the same rate that is recommended by the Congressional Budget Office, which is based on an estimate of the long-term cost of borrowing for the federal government (see

"Treasury quotes" 2003) and is generally considered a conservative estimate of the long-term real market risk-free interest rate. (Results were sensitivity tested to discount rates between 0 and 7%, along with sensitivity tests of a variety of other model parameters.) The planning period was taken as 100 years for mitigation of important structures and infrastructure and 50 years for all other mitigation measures, regardless of property age. Avoided statistical deaths and injuries were valued using FHwA (1994) figures, brought to 2002 constant dollars (using the consumer price index), but not time discounted primarily because this would imply a death or injury in the future is worth less than today.

Translating injuries and loss of life into quantifiable dollar figures is difficult. Estimates of the value of life vary greatly—from $1 to $10 million depending on the agency making the assessment or the use of the figure (see Porter 2002 for discussion). One of the more applicable figures is from a study for the Federal Aviation Administration (1998), in which the authors select a value of $3 million per statistical death avoided, in order to value the benefit of investment and regulatory decisions.

Quantifying the costs of injuries is equally problematic. Little research has focused specifically on the cost of injuries from disasters. However, the Federal Highway Administration (1994) published a technical report that provided figures of estimated costs of damages in car accidents. These comprehensive costs include, but are not limited to: lost earnings, lost household production, medical costs, emergency services, vocational rehabilitation, and pain and lost quality of life (FHwA 1994). This severity scale, however, does not map directly into the HAZUS 4-level scale, and as such has been modified for this project. Using a geometric mean approach to combine categories, minor and moderate severity costs were merged for the HAZUS 1 level; the serious severity level was used for HAZUS level 2; and severe and critical severities were merged to form the HAZUS level 3 estimate. As discussed earlier, the FAA value of human life was used to represent the HAZUS level 4 category.

Regarding the decision not to discount deaths and nonfatal injuries avoided, there is substantial disagreement over whether or at what rate one should discount future avoided deaths and injuries. Farber and Hemmersbaugh (1993) provide a survey of studies suggesting that people would discount future lives saved at rates varying between 8 and 0%, and in some cases negative values (see also Van Der Pol and Cairns 2000). Some argue that because of long-term increases in productivity, the present value of lifetime earnings (part of the statistical value of fatalities avoided) should be discounted at a lower rate than other future values (Boardman et al. 2001). Several authors argue (e.g., Cowen and Parfit 1992) that discounting human lives is ethically unjustified. Absent a strongly defensible basis and consensus for discounting avoided statistical deaths and injuries, it seems reasonable not to do so.

Grant Selection

This study addresses all FEMA-funded mitigation grants that satisfy the following criteria: (1) the grant was listed in the National Emergency Management Information System (NEMIS) database provided by FEMA in July 2003; (2) the grant was associated with disaster number 993 (Midwest floods of June 1993) or higher; and (3) the grant was intended to reduce future losses associated with earthquake, flood, or wind risk from hurricanes or tornadoes, as determined using FEMA's project-type code in NEMIS. Where the project-type code did not reveal the hazard to be mitigated, the hazard was assumed to be the same as that of the declared disaster, and this assumption was crosschecked by a review of the grant application.

During the period studied, FEMA conducted three programs in support of hazard mitigation: the postdisaster Hazard Mitigation Grant Program (HMGP) and two predisaster programs, Project Impact (PI) and the Flood Mitigation Assistance (FMA) program. The HGMP, the oldest and largest of the three programs, was created in 1988 to assist states and communities in implementing long-term hazard mitigation measures following presidentially declared disasters. Between 1993 and 2003, FEMA, in partnership with state and local governments, obligated $3.5 billion for states and communities to invest in a variety of eligible earthquake, flood, and wind mitigation activities selected as the most beneficial by local officials.

Project Impact was a program funded between fiscal years 1997 and 2001. Unlike the HGMP, which provides funding after disasters, PI supported the development of predisaster mitigation programs. In total, 250 communities across all states and some United States territories received $77 million in grants. The one-time Project Impact grants were considered seed money for building disaster-resistant communities and encouraged government to work in partnership with individuals, businesses, and private and nonprofit organizations to reduce the impact of likely future natural disasters.

The Flood Mitigation Assistance Program (FMAP) was created as part of the National Flood Insurance Reform Act of 1994 with the specific purpose of reducing or eliminating claims under the National Flood Insurance Program (NFIP). The FMAP provides funding to assist states and communities in implementing measures to reduce or eliminate the long-term risk of flood damage to buildings, manufactured homes, and other structures insurable under the National Flood Insurance Program. Annual funding of $20 million from the National Flood Insurance Fund is allocated to states that, in turn, obligate it to communities.

Note that our study did not estimate the benefits of all FEMA mitigation grant expenditures during the study period. Approximately $200 million in grants were not addressed for any of several reasons but primarily because they did not address one of the three hazards (earthquake, flood, and wind) examined in this study. Also, this paper reports only on the benefits of HMGP grants. The reader is referred to MMC (2005) for a discussion of PI grants.

HMGP grants comprise most of the grants and funds in the population of grants considered. The amount of funds is determined during the recovery period following a disaster declaration. During the 10-year period considered, the amount allocated for mitigation grants was approximately 15% of the amount spent by the federal government for emergency response and recovery programs. The nature of grants is influenced by the grantees (states), and the subgrantees (state agencies, local governments, and certain private nonprofit organizations) that prepare and submit applications to the states. FEMA asks states to determine priorities and to evaluate subgrantee applications for consistency with these priorities and other state requirements, and with FEMA requirements. Grant applications are accepted beginning several months after the disaster declaration. There may be more than one solicitation period and the solicitation process may last a few years. The rigor and time required for state-level application review depends on the number and complexity of applications received and the state's review capacity. FEMA only considers the applications forwarded by the states and generally acts within a few months,

Table 1. Mitigation Costs and Sample Size by Hazard (in 2004 Dollars)

		Population		Sample	
Hazard	Type	Count	Cost ($M)	Count	Cost ($M)
Wind	Project	1,190	280	42	38
	Process	382	94	21	38
Flood	Project	3,404	2,204	22	84
	Process	108	13	6	2
Earthquake	Project	347	867	25	336
	Process	48	80	20	74
Total		5,479	3,538	136	572

unless a proposed project affects historic or environmental resources and triggers federal reviews that might require a year or more. After application approval, the subgrantee must provide the matching funds and execute the project. Some mitigation projects may take years to complete and in some instances may involve funds derived from more than one disaster declaration. Projects undertaken reflect the priorities of the subgrantees and the states and their values, and do not necessarily reflect a policy to maximize the benefit-cost ratio.

Grant data were acquired in electronic format for 5,479 approved or completed grants to mitigate flood, earthquake, or wind risk. The data were stratified by hazard type (flood, earthquake, or wind) and mitigation type (project or process activity). A selection of 357 mitigation grants was made for detailed examination based on a stratification scheme and minimum sample size criterion developed early in the project. The study investigators collected additional data on as many of these grants as possible (see MMC 2005, Chap. 3).

A rigorous random sampling technique was applied to select these 357 grants (see MMC 2005, Chap. 4 for details). In particular, grants in each stratum were sorted in order of increasing cost. The stratum was then divided into a number of substrata of approximately equal total cost, and sample grants were selected at random from within each substratum. The sample grants thus represent the distribution of mitigation costs and to ensure the inclusion of low, medium, and high-cost mitigation efforts in each stratum. FEMA was able to provide paper copies of 312 grant applications. The paper grant-application files tended to contain more descriptive information about grants than did the NEMIS database. (All paper grant applications and the NEMIS database provided by FEMA were forwarded by the writers to the Washington, D.C. office of NIBS, where they can be reviewed by interested parties.) Of these, 136 contained sufficient data to perform a benefit-cost analysis. Data were extracted from these paper files and transcribed to electronic coding forms in a detailed and structured fashion. The form for project mitigation activities contained 200 data fields for each property or location mentioned in the grant application. Eventually, 54,000 data items were extracted for the stratified sample, consisting of 1,546 properties in project mitigation activities and 387 distinct efforts in process-type activities, representing nearly $1 out of every $6 spent on hazard mitigation in the population of grants examined here.

Table 1 summarizes the distribution of these grants by mitigation type and hazard for the entire population of grants that satisfy the criteria listed above and for the sample that was selected to represent the population. The table distinguishes grants that involve the actual mitigation of risk (*project* mitigation activities) from activities involving support functions (*process* mitigation activities). Project activities include physical measures to avoid or reduce damage resulting from disasters. Typically they involve acquiring and demolishing, elevating, or relocating buildings, lifelines, or other structures threatened by floods; strengthening buildings and lifelines or their components to resist earthquake or wind forces; or improving drainage and land conditions. Process activities lead to policies, practices, and other activities that reduce risk. These efforts typically focus on assessing hazards, vulnerability, and risk; conducting planning to identify mitigation efforts, policies, and practices, and to set priorities; educating decision makers, and building constituencies; and facilitating the selection, design, funding, and construction of projects. See MMC (2005, Chap. 2) for a more extensive discussion of the distinction between project and process grants.

Sample Results

Sampled Grants for Project Mitigation Activities

This section summarizes results for grants for project mitigation activities only for earthquake, wind, and flood. "Sampled Grants for Process Mitigation Activities" discusses the sampled grants for *process* mitigation activities for these hazards.

The results of the benefit-cost analysis of FEMA project grants are discussed below. Although some details are presented at the individual grant level, the benefit calculations and the benefit-cost ratio results are valid only at the aggregate level. This is consistent with the general nature of statistical studies of this kind. The benefit-cost ratios calculated in this part of the study were independent of those provided in grant applications. There were several reasons for this, including the need to develop and implement an independent methodology for estimating future benefits, and the fact that the focus of this study was on aggregate benefits and not on the benefits of individual grants. A list of methods used to measure each benefit type for each hazard is presented in Table 6.

Grants for Earthquake Project Mitigation Activities

The earthquake stratum of grants for project mitigation activities includes grants for both structural activities (e.g., base isolation of public buildings) and nonstructural activities (e.g., retrofit of pendant lighting in schools). Overall, the stratum sample included 25 grants involving 128 buildings. Pendant lighting projects in schools accounted for the majority of the buildings analyzed in this stratum, with one grant addressing the replacement or mitigation of seismically vulnerable light fixtures in 78 buildings. Higher-cost grants included seismic upgrades and seismic safety corrections of hospitals, university buildings, and other public buildings.

HAZUS MH was the primary methodology used in estimating property damage, direct and indirect business interruption losses, and some societal impacts such as number of deaths and injuries. It was applied using structural, economic, and societal information and data obtained from grant applications found in FEMA files, and supplemented with published data on some key projects.

New methods were developed for estimating some types of avoided losses, including business interruption impacts associated with utility outages, damage to pendant lighting and ceilings, environmental/historical benefits, and some societal benefits. The simple average benefit-cost ratio for the 25 grants in this stratum is 1.4, with a standard deviation of 1.3. The total benefit for this stratum is $1.2 billion. Individual grant benefit-cost ratios range from near zero for a nonstructural retrofit to an electricity substation (intended to reduce physical injury to workers) to 3.9 for a nonstructural retrofit of a hospital. Note that the presence of individual grants with estimated BCR <1 does not indict FEMA grant making. Not all details considered in the original grant application necessarily appear in the paper copy of the grant application transmitted to the project team.

HAZUS MH was used to estimate property damage avoidance (benefits) due to the structural upgrades. The total property loss reduction for this stratum is $319 million. Property loss reduction alone, however, was not sufficient for the average benefit-cost ratio from mitigation measures in this stratum to exceed 1.0. Of the 25 hazard mitigation grants in the earthquake project stratum, three avoided business interruption. The cases where business interruption was applicable included impacts on utilities and hospitals; no conventional business activities other than these were in the sample. (This estimation here and for other hazards excludes business interruption caused by damage to public buildings such as police and fire departments, civic arenas, and schools. These public sector activities, although not priced as a business product or service, do yield commensurate value even if usually not transacted through the market. However, they have been omitted from business interruption calculations because, in the aftermath of a natural disaster, most of their functions are provided by other locations or "recaptured" at a later date. Moreover, payments for major inputs continue even when the original facility is closed e.g., wages to unionized employees.) In addition, an inherent assumption of the HAZUS MH methodology is that only *structural* mitigation results in business interruption benefits. The vast majority of *nonstructural* mitigation measures in this stratum are for pendant lighting in schools, and are assumed only to affect casualty rates.

For the three applicable cases in the earthquake project grant sample stratum, business interruption benefits average $52.9 million, and range from a low of $1.3 million for a pump station to a high of $139.5 million for a hospital. Here and elsewhere in the study, we factored in some aspects of "resilience" to business interruption, or the ability to mute potential losses through inherent features of business operation (e.g., input substitution or using excess capacity) as well as adaptive behavior (identifying new sources of supply or making up lost production at a later date) (see, e.g., Rose 2004a). Business interruption benefits contribute about 10% to the overall average benefit-cost ratio for this stratum.

The largest component of benefits in the earthquake project stratum was the reduction of casualties, which accounted for 62% of the total benefits. Analysis shows that a reduction of about 542 injuries and 26 deaths in this stratum sample is expected. Extrapolating to the entire stratum population, it is estimated that these grants result in avoiding 1,399 injuries and 67 deaths. The mean total benefit per grant is about $6.3 million, with a standard deviation of $6.4 million. The projects with zero calculated casualty benefits included electrical substation upgrades, a school arcade replacement, and nonstructural mitigation activities to emergency power and communication facilities (rather than patient services) in a hospital.

Three earthquake grants in the sample provided environmental or historical benefits, including improving water quality, protecting historic buildings, and positive health benefits. The highest environmental benefit was for an earthquake retrofitting of a police headquarters building ($293,000), while the lowest pertains to health benefits of a hospital retrofit. The average benefit of these three grants is nearly $143,000, and they accounted for less than 1% of the total benefits in the earthquake project grant stratum. No significant outliers exist in the earthquake project stratum, with the exception of two nonstructural mitigation grants. These two grants did not provide much property protection, almost no casualty reduction, and no protection at all against business interruption. Those projects with low benefit-cost ratios include some cases of nonstructural mitigation intended primarily for life safety. Other cases of this same type of mitigation yield some of the higher benefit-cost ratios, along with structural retrofit of large buildings. The seeming incongruity of the benefits of nonstructural retrofits is explained primarily by differences in the number of individuals at risk of death and injury.

For this stratum, as well as for the others below, the overall approach was conservative (i.e., we made our decisions about assumptions, data, inclusion, in nearly all cases so as to err on the side of obtaining low benefit estimates). In this stratum, estimates of the diffusion of university research and of demonstration projects, as well as several types of societal impacts related to psychological trauma, were omitted because there was no adequate means of quantifying these measures. Also omitted in this and other strata were: indirect property damage (e.g., prevention of ancillary fires), avoided negative societal impacts relating to psychological trauma (e.g., crime, divorce), air quality benefits (improvements in visibility and health due to reduced burning debris), benefits from reduced disposal of debris (land quality), and aesthetic benefits including visibility and odors of reduced debris.

Grants for Wind Project Mitigation Activities

Although several mitigation measures are included in the sample grants for the wind project grant stratum, the majority deal with hurricane storm shutters and saferooms. HAZUS MH readily handles property benefit calculations for hurricane storm shutters. However, supplemental methodologies were developed by the study investigators to estimate property damage impacts of tornadoes and casualty impacts for both hurricanes and tornadoes. Benefit transfer methods were used to estimate environmental/historic benefits.

The simple average benefit-cost ratio for the 42 grants in the wind project stratum was 4.7, and the standard deviation was 7.0. The total benefit for this stratum is $1.3 billion. Individual grant benefit-cost ratios range from less than 0.05 for retrofit of a police department building to greater than 50, for a variety of utility protection measures.

Benefit-cost ratios outside these bounds were ignored for the purpose of calculating the stratum-average benefit-cost ratios, which results in a conservative estimate. That is, estimated benefits would have been greater had these samples been included. The projects with a benefit-cost ratio less than 0.05 or greater than 50 are referred to here as outliers; all projects with benefit-cost ratio between 0.05 and 50 are referred to as the censored set. The bounds of 0.05 and 50 were initially selected somewhat arbitrarily. However, when one calculates the 1st and 99th percentiles of the lognormal distribution with the same moments as the censored set (±2.3 SD), all members of the censored set have benefit-cost ratios within these 1st and 99th percentiles, so the bounds are in a way "stable." Note that the benefit-cost ratios of the censored set are approximately lognormally distributed, passing a Kolmogorov–Smirnov goodness-of-fit test at the 5% significance level.

Several of the grants that had large benefit-cost ratios (>10), including all four outliers that exceeded 50, were cases of electric utility mitigation, such as relocating utility power lines below ground. In these cases, property damage savings were relatively small, but the business interruption savings were large. A downed power line, or a substation that has been disrupted because of a hurricane, can cause the economy of a city to come to a halt for days (Rose et al. 1997). Even the prevention of an outage of a few hours can pay for itself several times over in some instances.

Property loss benefits can be significant, with reductions measuring up to four times the cost of the retrofit. The sample average benefit-cost ratio associated with property loss reduction is 0.59. The estimated total reduction in property loss for all wind project grants (not just those in the sample) is $166 million.

Casualty benefits apply to 25 grants in the wind stratum. All of these projects are either hurricane shelters or tornado saferooms. The hurricane grants involved mitigation of multiple properties, usually schools; however, not all of the schools are on the shelter inventory. The methodology calculated benefits for only those schools that also serve as hurricane shelters. Collectively, the schools that met this condition were able to shelter, at capacity, about 33,189 evacuees. The tornado grants involved the building of saferooms in public and private spaces, the majority of which were community shelters (sheltering 750–1,000) with one notable exception that sponsored the construction of saferooms in hundreds of private residences.

Considering both types of wind project grants—hurricane and tornado—together, mitigation activities reduced casualty losses in the sample by about $108 million, or an estimated $794 million for all wind project grants. The per-project mean casualty benefit is $4.3 million.

Some intangible benefits of shelters could not be quantified, and were therefore excluded from the benefit-cost analysis. Regardless of the financial benefit of sheltering, shelters are beneficial by reducing uncertainty and stress in those at risk. In addition, available hurricane shelter space keeps people off the highways during dangerous periods. More important, shelters offer the only safe haven for those without the financial means to take other protective measures.

Historical benefits were applicable to only one wind hazard grant: door and window protection for an historic town hall (a total estimated benefit of $115,000). For the wind project grant stratum overall, however, historic benefits contributed little to the average benefit-cost ratio.

Estimates of casualties avoided because of grants for wind mitigation project activities are high compared to the number of lives lost annually from high wind in the United States. In this study, the estimated casualties avoided are all tornado related. Because the body of peer-reviewed scientific literature relating to probabilistic estimates of loss reduction from tornado mitigation is scant relative to that of other natural hazards covered in the study, the project investigators developed loss models without benefit of years of input from the scientific community in developing, testing and validating modeling techniques.

Because of these issues, ATC contracted with Professor James McDonald of Texas Tech University, a noted wind engineering expert, to review and comment on the entire loss estimation methodology for tornado. Because of this review, changes were made to the methods used to quantify tornado impact areas. The Project Management Committee and the Internal Project Review Panel agree that the model used is logical. Avoided casualties have a limited effect on the aggregate results of the current study. The sensitivity analysis found that the benefit-cost ratio for the stratum of grants for wind project mitigation remained above 1.0 when casualty rates were reduced an order of magnitude lower than the estimated rates. If only 10% of the estimated benefits attributed to avoided casualties are counted, the benefit-cost ratio for grants for wind-project mitigation activities would decline from 4.7 to 2.1. Moreover, given the relatively small number and size of grants for wind mitigation, the benefit-cost ratio of all mitigation programs would be reduced from 4.0 to 3.8.

Grants for Flood Project Mitigation Activities

HAZUS MH damage functions formed the basis for estimating property damage due to flooding. The hazard calculations, however, were performed outside of the HAZUS MH flood module because this component was not available at the time of this study. Instead, an alternative methodology was developed that used a probabilistic approach to locate properties in the flood plane and to estimate the expected distribution of flood heights. Casualties and displacement costs, and historic site and environmental benefits were calculated separately using the methodologies summarized in MMC (2005, Chap. 4). Because all mitigation measures applied to residential properties, no business interruption benefit was calculated.

The study investigators coded 71 project files (consisting of 990 properties) into the project database. Approximately two-thirds, 625 properties, were geocoded through a combination of address matching tasks: (1) matching to previously located properties in the NEMIS database; (2) geocoding using TIGER street data; and (3) matching addresses with geographic coordinates using online services such as MapQuest.

Out of the 625 geocoded buildings, 486 were within an acceptable distance to allow mapping in the FEMA Q3 digital flood map and the USGS National Hydrography Dataset (NHD) stream data. Several projects were subsequently eliminated from the analysis because of insufficient data. A final selection of 483 properties corresponded to 22 grants. For each flood project, only properties that matched all the above criteria were analyzed for direct property damage.

The number of geocoded properties within the acceptable distance in a single grant ranged from 1 to 133, with a mean of 42 and a standard deviation of 33. The property benefits realized for grants range from $0.19 to $1.1 million. The average benefit per property ranged from $0.13 to $0.74 million, with an average benefit of $0.28 million, and a standard deviation of $0.14 million. The only significant outlier was the acquisition of a school, with a total benefit of $18.7 million.

Grants for flood acquisition projects also reduce the societal impacts of flooding by reducing injuries to the residents of the properties. For the flood project grant stratum, 22 grants had enough data to estimate casualty reduction benefits. The grants varied in size, with some mitigating many properties and others only a few. Overall, buying these properties reduced approximately 68 injuries for a total benefit of $12.3 million. On average, the 22 grants have a mean benefit of $0.56 million and standard deviation of $0.85 million. The large standard deviation for flood project grants results from the large grant size range.

The majority of the grants in the flood project grant stratum were for residential structures that had experienced repeated flooding. Costs associated with residential flooding included displacement costs for the families to relocate while their homes underwent repair. By buying out repeatedly flooded properties, mitigation activities reduced displacement expenditures. Twenty two sampled grants included sufficient information to estimate displacement costs. The total sampled stratum benefit is $2.3 million.

Sixteen of the flood mitigation grants yielded environmental benefits, and none yielded historical benefits. Fourteen of the environmental benefits pertained to establishing wetlands following the removal of structures, rather than direct environmental benefits of reduced flooding per se. The environmental benefits of these grants were estimated by applying wetland values from the literature to each acre created. Conservative assumptions were made about the wetland acreage created for each property purchased, the percentage of these acres that actually function as wetlands, and the number of years that the acreage would function as such. Strictly speaking, these are side effects of mitigation, rather than intended consequences. This analysis could have listed them as offsets to mitigation costs, but it is less confusing to list them under benefits.

The grant with the highest environmental benefit was for the purchase and removal of 262 flooded properties (approximately $0.32 million), while the lowest benefit was for the purchase and removal of one flooded property (approximately $6,000). The average environmental benefit associated with these 16 grants is nearly $96,000.

The total of all benefits realized for each grant ranged from $0.19 to $116.5 million, with a standard deviation of $27.3 million. The high standard deviation is directly attributable to the differences in the number of acquisitions.

All individual flood grants had benefit-cost ratios greater than 1.0, with an average benefit-cost ratio of 5.1, a minimum of 3.0, a maximum of 7.6, and a standard deviation of 1.1.

Sampled Grants for Process Mitigation Activities

Process grants do not yield benefits themselves, but rather provide the basis for subsequent mitigation action. The benefits estimated here reflect only a portion of eventual benefits, the cost of which is often borne by nonfederal government agencies or the private sector. The essence of the process benefit estimation procedure is that process grants have the same benefit-cost ratio as the eventual mitigation activities that they inspire. The analysis was based on what we call the “surrogate benefit” approach. While this study relies predominately on standard applications of benefit estimate transfer, the application of this approach to estimating the benefits of grants for process mitigation activities, however, stretches this method to its limits because there are no studies that measure the benefits of process activities. Studies of the implementation of process activities in related areas, or surrogates, (e.g., radon risk communication) were used instead.

Only the following three major types of process grants were evaluated:

- Information/warning (risk communication);
- Building codes and related regulations; and
- Hazard mitigation plans.

These three types of grants accounted for more than 85% of all process grants.

Grants for Earthquake Process Mitigation Activities

Twenty earthquake grants for process mitigation activities were evaluated. The average benefit-cost ratio of the sample is 2.5. Benefit-cost ratios for individual grants ranged from 1.1 for an engineering task force, to 4.0 for several grants for hazard mitigation plans and building codes. The surrogate benefit methodology analyzes each grant in its entirety and does not separate out the different types of benefits as was done for grants for project mitigation activities. The methodology does not lend itself to the calculation of the standard deviation of benefit-cost ratio, so that figure was omitted here. The majority of grants for earthquake process mitigation activities are for mitigation plans and improvement of building codes and regulations. The only grant for information activities was for vulnerability evaluations.

Grants for Wind Process Mitigation Activities

Twenty-one wind-related grants for process mitigation activities were evaluated. The average benefit-cost ratio is 1.7. Individual grant benefit-cost ratios ranged from 1.1 for risk communication grants to 4.0 for code development. Ten of the grants in this stratum were for hazard mitigation plans, and nine were for risk communication activities. The standard deviation of benefit-cost ratio was omitted because the surrogate benefit methodology does not lend itself to this calculation.

Grants for Flood Process Mitigation Activities

Only six process grants for flood mitigation activities were evaluated. The small number reflects the fact that the majority of flood hazard process grants originally sampled were Project Impact grants, which were subsequently dropped from the benefit-cost analysis of FEMA grants study component because sufficient data for performing a complete analysis were lacking in the grant files. The average benefit-cost ratio for this stratum is 1.3, with little variation across individual cases. Five of the six process grants were mitigation plans and the other was for streamlining a building permit process. Again, the standard deviation of benefit-cost ratio for process grants was omitted.

Summary of Results for Process Mitigation Activity Grants

A conservative estimate of the benefit-cost ratio for most process grants dealing with mitigation planning is about 1.4 (see MMC 2005, Chap. 4). This estimate is based on the Mecklenburg (Canaan 2000) studies, the study by Taylor et al. (1991), and the URS Group (2001) report, which is most applicable to multihazard planning grants. For grants for activities involving building codes a conservative estimate is higher than for multihazard planning grants, at a value of approximately 4. This estimate is an average based on the lower end of benefit-cost ratios provided in the studies by Taylor et al. (1991), Porter et al. (2006), and Lombard (1995). The estimate is likely conservative because of the very wide range of potential benefit-cost ratios estimated for actual adopted building codes and savings in property damage from hurricanes of different size categories, including a few very high benefit-cost ratios for building codes (Lombard 1995). With regard to a grant for seismic mapping, another estimate to confirm this range for the benefit-cost ratio is 1.3 based on the Bernknopf et al. (1997) study of the value of map information, which assumes that property value changes fully capitalize the hazard disclosure effects via the housing market.

Grants for building code activities likely will have a larger benefit-cost ratio than grants for information/warning and hazard mitigation plan activities. If a grant is inexpensive, it is quite likely that its net benefits will be positive, based on the Litan et al. (1992) study of earthquake mitigation, which found average benefit-cost ratios of about 3. Therefore, any small grant for process activities that does not have negative consequences in obtaining mitigation will only slightly raise costs and, therefore, only slightly reduce the benefit-cost ratios in this category. As Lombard (1995) notes, the benefit-cost ratio in some cases (e.g., smaller homes), and some hurricane categories (on a scale of 1–5), could be very large. An example is a benefit-cost ratio of 38 for anchorages for a Category 2 hurricane. Lombard’s ratios are based on actual costs of mitigation, not related to grants per se, and there is no way to know how the probability of adopting specific building codes is changed by the grant.

Based on logic and effectiveness found in other contexts (Golan et al. 2000), there is reason to believe that grants for process mitigation activities provide positive net benefits in many

Table 2. Scaleup of Results to All FEMA Grants (All $ Figures in 2004 Constant Dollars)

	Project grants			Process grants			
	Quake	Wind	Flood	Quake	Wind	Flood	Total
Sample grant count	25	42	22	20	21	6	136
Sample grant benefit ($M)	365	219	388	93	44	2	1,111
Population grant count	347	1,190	3,404	48	382	108	5,479
Population grant cost ($M)	867	280	2,204	80	94	13	3,538
Population grant benefit ($M)	1,194	1,307	11,172	198	161	17	14,049
Total benefit-cost ratio (BCR)*	1.4	4.7	5.1	2.5	1.7	1.3	4.0
Sample standard deviation of BCR	1.3	7.0	1.1	n.a.[a]	n.a.[a]	n.a.[a]	n.a.[a]

[a] n.a.=not applicable because of estimation method used.

situations. Project mitigation activities in many cases would never take place if a process activity had not generated the initial plan or building code that led to implementation. A common sense conclusion is that when net benefits from mitigation in a particular category, exclusive of a grant for process activities, are large then a small grant certainly cannot reduce the net benefits by much; hence, any grant in that category is likely to be positive.

Several caveats are warranted. First, in the literature search, no studies were found that specifically and clearly estimated the benefits of a hazard mitigation process activity. To estimate process activity benefits would require knowledge of how the probability of decision makers adopting a mitigation strategy changed after implementation of a process activity. Possible key differences have been noted between radon risk communication and a natural hazard risk warning. In general, the information that is available, even for conventional natural hazards, largely pertains to benefits and costs for mitigation projects or mitigation costs in general, i.e., not related to any grant activity. Second, there is still not enough information in the literature on the effectiveness of process activities to induce adoption of a mitigation action to generalize in the above categories. Last, there is regional variation in rates of adoption of mitigation practices because of differences in conditions, experience, and perceptions (see the community studies discussion in MMC 2005; Chap. 5).

Extrapolation of Sample Results to Population

The results presented in previous sections were scaled to the population of grants using the following approach. Let i denote an index for a grant, j denotes an index for a stratum (e.g., earthquake project grants), C_j denotes the total cost for all grants in that stratum, N_j denotes the number of grants in the sample for that stratum, b_i denotes the estimated benefit of sample grant i (in stratum j), and c_i denotes the recorded cost for the sample grant. Then B_j, the benefit from stratum j, is estimated as

$$B_j = \frac{C_j}{N_j}\sum_{i=1}^{N_j}\frac{b_i}{c_i} \qquad (1)$$

Table 2 presents the results. It indicates that the present value discounted benefits for grants for FEMA hazard mitigation activities between mid-1993 and mid-2003 is $14.0 billion. This is juxtaposed against grant costs of $3.5 billion, for an overall benefit-cost ratio of 4.0. Table 2 also summarizes the calculation of stratum benefit-cost ratios. The benefit-cost ratios for project mitigation activities in descending order, are 5.1 for flood, 4.7 for wind, and 1.4 for earthquake. Benefit-cost ratios are the reverse order for grants for process mitigation activities, with 2.5 for earthquake, 1.7 for wind, and 1.3 for flood.

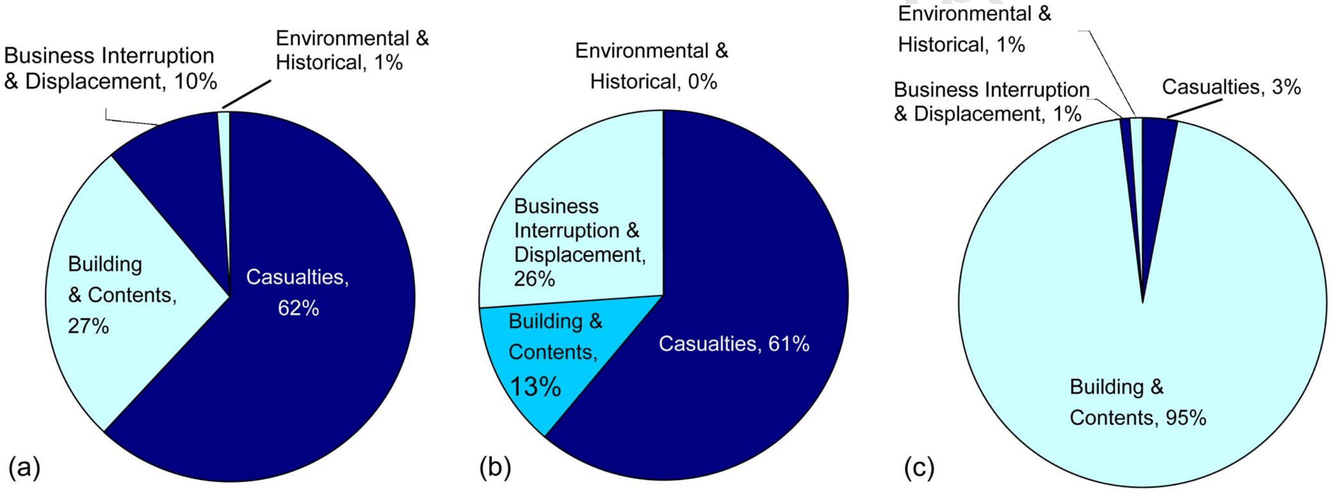

Fig. 1. Contribution to benefit-cost ratio by factor for: (a) earthquake; (b) wind; and (c) flood

Table 3. Summary of Benefits and Costs by Hazard

Hazard	Cost ($M)	Benefit ($M)	Benefit-cost ratio
Earthquake	947	1,392	1.5
Wind	374	1,468	3.9
Flood	2,217	11,189	5.0
Total	3,538	14,049	4.0

As shown in Fig. 1, in terms of contribution to the benefit-cost ratio overall, casualty reduction was by far the dominant factor in earthquake and wind, and avoidance of property damage was the dominant factor in flood. This is attributable to a great extent to the life safety feature of most earthquake, hurricane and tornado project grants, and the property emphasis of flood grants (in addition to the longer warning time for the latter). Given the sample studied, business interruption avoidance was significant in earthquake and wind, but not for flood. This stems from the fact that the vast majority of flood project grants were for buyouts of residences in floodplains. Environmental and historic benefits proved to be very minor in dollar terms, but still do affect a large number of people in each affected community.

Breakdown of Results

The results are summarized by grants for each hazard type in Table 3, which shows that overall, mitigation grants for each hazard have benefit-cost ratios greater than one, with the grants for flood mitigation being the most cost-beneficial (BCR=5.0). Table 4 summarizes the benefit-cost analysis results by major mitigation type. It shows that both project and process activities are cost beneficial, with projects having an average benefit-cost ratio of 4.1, and processes having an average benefit-cost ratio of 2.0. Overall, flood grant benefits (both project and process) represent 80% of the total FEMA grant benefits. Wind and earthquake benefits each represent approximately 10% of the total.

In assessing the results, recall that grants for process activities (including Project Impact) represent only 10% of the total number of FEMA grants in the NEMIS database (the total population). Moreover, they represent only about 5% of the total FEMA grant expenditures nationwide. As shown in Table 4, process grant benefits represent 2.7% of FEMA grant total benefits to the nation. This is consistent with the result that the benefit-cost ratio for project grants is estimated to be twice as high as for process grants.

Deaths and Injuries

Table 5 highlights the reduction of casualties as a result of the mitigation activities conducted under the grants in the sample and for the entire population of grants. Because the NEMIS database does not include data on the number of people affected by each grant, it was necessary to estimate reduction in casualties for the population of grants using grant costs. Total reduced casualties among the population of grants is estimated as the reduction among the sample grants times the ratio of population cost to sample cost.

Table 4. Summary of Benefits and Costs by Mitigation Type

Type	Cost ($M)	Benefit ($M)	Benefit-cost ratio
Project	3,351	13,673	4.1
Process	187	376	2.0
Total	3,538	14,049	4.0

Table 5. Estimated Reduction in Casualties by Grants for Both Project and Process Mitigation Activities

	Injuries	Deaths
Earthquake sample	542	26
Population	1,399	67
Flood sample	63	0
Population	1,510	0
Wind sample	275	24
Population	1,790	156
Total samples	880	50
Population total	4,699	223

Mitigation grants in the population of FEMA grants will prevent an estimated 4,699 injuries and 223 deaths over the assumed life of the mitigation activities, which in most cases is 50 years. As illustrated in Table 5, grants for wind mitigation activities will prevent the most injuries (1,790) and the most deaths (156). As with any casualty figures, these estimates require caution, as they are based on a scientifically sound methodology, but are difficult to validate because of limited available empirical data. The grants examined not only benefit society by reducing financial expenditures, but also, and equally as important, reduce associated stress and family interruption. While consideration was not able to be given to the financial benefit of these reductions, they are an important component of the benefit of mitigation.

Net Benefits to Society

The overall benefit to society for all 5,479 grants is approximately $14.0 billion, and the cost to society is $3.5 billion. The net benefit to society of FEMA-funded mitigation efforts is thus $10.5 billion, which includes the financial benefits and dollar-equivalent benefit of saving 223 lives and avoiding 4,699 nonfatal injuries.

Interpretation of Results

Benefit-cost ratios vary significantly across hazards. One major reason is that the type of avoided damage differs significantly between earthquakes, hurricanes, tornados, and floods. For example, 95% of flood benefits are attributable to avoided losses to structures and contents, and only 3% is for casualty reduction, as opposed to casualty reductions slightly over 60% each for the cases of earthquake and wind hazards. The cost effectiveness of measures to reduce property damage from frequent flooding is higher than that for reducing casualty in the wind and earthquake grants sampled in our study. This is in part because of the lower variability of factors affecting structures (which are of a fixed location, size, etc.) than of casualties (where occupancy rates vary by time of day), thereby making it harder to protect the latter. For example, mitigation grants to replace pendant lighting in schools provide potential protection but did yield actual benefits only for earthquakes that occur during hours when the buildings are occupied. In a similar vein, a higher proportion of wind mitigation grants is for the purpose of reducing the vulnerability of electric utilities to hurricane and tornado winds, than is the case for earthquakes. The largest individual grant benefit-cost ratios found in our study stemmed from reduced business interruption associated with damage to utilities.

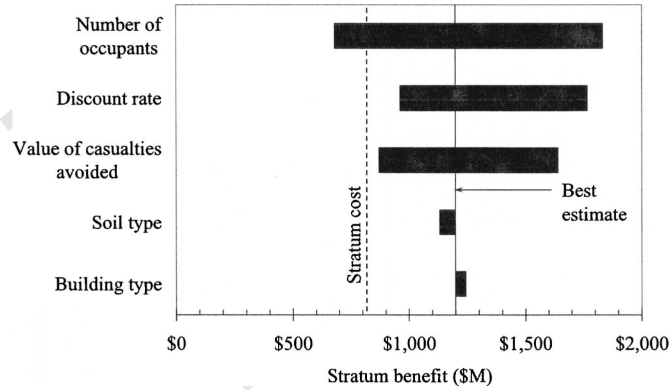

Fig. 2. Sensitivity of benefit to uncertainties (grants for earthquake project mitigation activities)

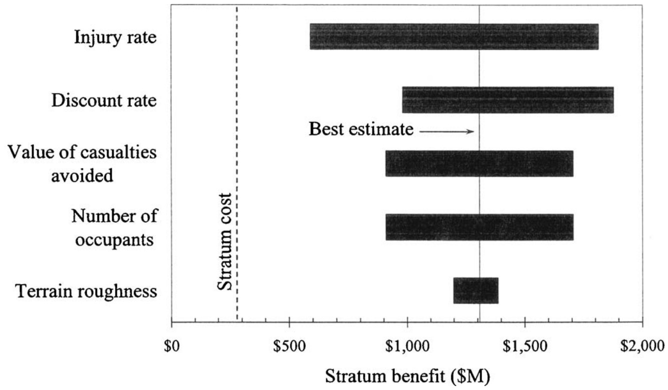

Fig. 3. Sensitivity of benefit to uncertainties (grants for wind project mitigation activities)

Flood mitigation grants have a higher probability of success, and hence a higher benefit-cost ratio because they pertain to properties with known histories of vulnerability in the heart of floodplains, and recurrence of floods in a given location is much more certain than for other hazards. Given that process mitigation grants have lower benefit-cost ratios than project mitigation grants across all hazard categories, the fact that process grants represented only 0.15% of total flood project mitigation benefits, in contrast to 1.2% of wind mitigation grant benefits, kept the flood process mitigation grants from pulling down the overall flood BCR as much as they did for overall wind benefit-cost ratio.

When considering why the BCRs for earthquake mitigation are lower than flood and wind mitigation, one must consider policy emphases (i.e., California's earthquake mitigation priorities and FEMA's flood mitigation priorities) and hazard probabilities. Most of the sampled earthquake grants were from California, where the state's priorities emphasized reducing casualties, and making schools and hospitals safer and more reliable. Local priorities emphasized retrofit of city-owned emergency facilities and administrative buildings. The bulk of earthquake grants went to school districts for nonstructural mitigation intended to reduce casualties, and government agencies for government-owned buildings, only a few grants had business interruption implications. Because seismic codes with seismic provisions have been followed for decades in California, these buildings are not too vulnerable to the less intense earthquakes estimated to occur with the frequency associated with floods (within the 100-year recurrence areas). Earthquake mitigation is motivated by concern for preventing casualties from large magnitude low probability earthquakes, not smaller frequent earthquakes. Earthquake retrofit projects reduce, but do not eliminate vulnerability to these rare events, so the increment of avoided physical damage is small.

This situation differs for flood mitigation, where many of the grants are to remove private structures from the 100-year or more frequent return hazard area (repetitive loss areas). Mitigation often eliminates flood damage except in the very large events, but our study placed less consideration on events that recurred less frequently than once in 100 year.

Our study found BCRs for grant activities related to electric utility mitigation projects to be much higher for wind than for earthquake. However, this is due to the higher prevalence of publicly owned utilities in areas relatively more vulnerable to wind hazard than in high-risk earthquake zones (as well as the idiosyncratic nature of an earthquake project grant in our sample oriented toward life safety). However, *potential* BCRs of future mitigation projects for public and private electric utilities are similar between wind and earthquake. Any comparison between BCRs must also consider these policy decisions and background conditions, in order to avoid mistaken generalizations that some hazards and mitigation types will always produce higher BCRs.

BCA focuses on the aggregates of benefits and costs, but their distribution is also important from a public policy standpoint (see, e.g., Rose and Kverndokk 1999). There are often large disparities in losses from natural hazards, with disadvantaged groups often bearing a disproportionate share, as dramatized most recently by the impacts of Hurricane Katrina. Thus, mitigation in general is likely to benefit lower income and other disadvantaged groups. Unfortunately, data were not available to evaluate the distribution of benefits across socioeconomic groups for grants in this study, and are generally not readily available for most mitigation activities.

Sensitivity Analysis

Uncertainties in the loss-estimation procedure lead to uncertainty in the estimated benefit. For this reason, it is reasonable to question how robust the results are to these uncertainties, i.e., how confident can one be that benefits exceed cost? Sensitivity analyses were performed on the analysis parameters that were judged most likely to most strongly influence the results. Figs. 2–4 illustrate how making different assumptions about each of these parameters affects the total estimated benefit for those that revealed

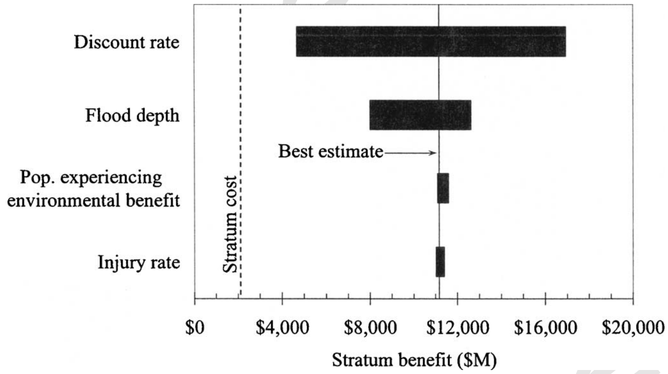

Fig. 4. Sensitivity of benefit to uncertainties (grants for flood project mitigation activities)

the greatest range of sensitivities. (Tests were performed on the sample, and the results applied to the population.) In each figure, there is a solid vertical line that represents the baseline (best) estimate of total benefit for all mitigation grants for that hazard. There is a dashed vertical line that represents the total cost for mitigation grants for that hazard.

Each black bar in the diagram reflects what happens to the total population estimated benefits for that hazard if one parameter (number of occupants, discount rate, etc.) is changed from a lower-bound to an upper-bound value. A longer bar reflects greater sensitivity of benefit to that parameter. Here, the "lower-bound" and "upper-bound" values are estimates of the 4th and 96th percentile values of the parameter in question for reason having to do with a subsequent mathematical procedure. In the case of the discount rate, the values shown are for 0% (higher benefit) and 7% (lower benefit). The parameters are sorted so that the longest black bar—the one for the parameter to which the benefit is most sensitive—is on top, the next most sensitive is second from the top, etc. The resulting diagram resembles a tornado in profile, and is called a tornado diagram.

The diagram does two things: first, it shows the conditions under which benefit exceeds cost. For example, Fig. 2 shows that benefit exceeds cost even if the discount rate is set to its upper bound (7%). Second, the baseline benefit and the values of benefit at the ends of the bars can be used to estimate the parameters of a probability distribution of total nationwide benefit. These parameters include the mean and standard deviation of total benefit, among others. To calculate them, a mathematical procedure called an "unscented transform" was used (Julier and Uhlman 2002). This procedure allows one to estimate the moments of a probability distribution of an uncertain output variable that is itself a deterministic function of one or more uncertain input variables. In the present application, the total nationwide benefit was treated as the output variable that is a function of the input uncertainties shown in Fig. 2. The sample points used in the unscented transform are the baseline benefit and the ends of the bars in Fig. 2. Note that the unscented transform produces a slightly different expected value of benefit than the baseline figure.

Results

Grants for Earthquake Project Activities

Results for earthquake project mitigation benefits are illustrated in Fig. 2. In the figure, the solid vertical line at $1.2 billion reflects the baseline benefit for earthquake project grants; the dashed line at $0.87 billion represents the cost of those grants. Total benefit is most strongly sensitive to number of occupants, then to discount rate, then to value of casualties. Notice that the only bar that crosses below the cost of mitigations is the first one, number of occupants. In all other cases, benefits exceed costs.

Using the unscented transform, it was found that the expected value of benefit from earthquake mitigation grants is $1.3 billion (approximately the same as the baseline figure of $1.2 billion). The standard deviation of benefit is $470 million. Assuming that benefit is lognormally distributed, the ±1 SD bounds of benefit are $850 million and $1.7 billion. Benefit exceeds cost with 0.83 probability. The expected value of benefit-cost ratio is 1.5, approximately the same as the baseline value of 1.4.

A word of caution regarding the comments about the probability that benefit exceeds cost. According to standard benefit-cost analysis, earthquake project grants are cost effective, because under baseline conditions, benefit exceeds cost by a ratio of 1.4:1. The additional diagram analysis merely acknowledges that the estimated benefit is uncertain, and that under most reasonable assumptions, benefits still exceed cost. Considering these uncertain parameters, earthquake projects are estimated to save $1.40 in reduced future losses for every $1 spent.

Grants for Wind Project Mitigation Activities

Fig. 3 shows the diagram for grants for wind project mitigation activities. In all cases, the benefit exceeds the cost. Wind project benefits are approximately equally sensitive to injury rate, discount rate, value of casualties, and number of occupants. The expected value of benefits is $1.3 billion, and the standard deviation is $560 million. Assuming a lognormal distribution, the ±1 SD bounds of benefit are $800 million and $1.8 billion. There is greater than 99% probability that the "true" benefit exceeds the cost, despite the uncertain parameters examined here. The expected value of benefit-cost ratio is 4.7. That is, every $1 spent on wind project grants is estimated to save almost $5.

Grants for Flood Project Mitigation Activities

Fig. 4 shows the diagram for grants for flood project mitigation activities. These benefits are more sensitive to discount rate than to uncertainties in flood depth. In all cases, the benefit exceeds the cost, i.e., under all reasonable assumptions about the values of these parameters, flood project grants are estimated to be cost effective. The expected value of benefit is $11 billion, and the standard deviation is $3.8 billion. Assuming lognormal distribution, the ±1 SD bounds of benefit are $7 and $15 billion. There is greater than 99% probability that the "true" benefit exceeds the cost, despite uncertainties in the parameters examined in this study. The expected value of the benefit-cost ratio is 4.8. That is, every $1 spent on flood project grants is estimated to save almost $5.

Other Sensitivity Analyses

Sensitivity analyses were not performed for direct business interruption for two reasons. First, direct business interruption estimates were derived to a great extent from direct property damage. Although not perfectly correlated, further sensitivity analyses would probably have been redundant. Second, there were few factors that could be subjected to sensitivity analysis of direct business interruption in HAZUS MH. Sensitivity analyses were performed for indirect business interruption with respect to the regional economy unemployment rate (as a proxy for excess production capacity). The analysis indicates that the overall stratum benefit-cost ratios are not sensitive to this parameter because of the small number of cases where business interruption was applied, the small size of indirect business interruption in all cases (except the few mitigation grants affecting utilities), and the narrow variation in this parameter.

Excess capacity is one of several sources of resilience Rose (2004a) to disasters factored into this study (recall the discussion in "Sampled Grants for Project Mitigation Activities"). Another is the "recapture factor" (the ability to make up lost production at a later date), which is automatically included in the HAZUS MH direct economic loss module (DELM). This recapture factor was also included in the HAZUS MH extension for utilities developed in this study, and in fact the recapture factor for services was increased in line with the study's conservative assumptions. Other aspects of resilience pertained to inventories, import of goods for which there is a shortage, and export of surplus goods. These were automatically computed in the HAZUS MH indirect economic loss module (IELM). Resilience effects were not separated out, because that was not the focus of this study. HAZUS MH default values were used for these parameters (inventories, import, and export of goods) and sensitivity analyses were not undertaken because HAZUS MH import and export resilience factors only affect indirect business interruption, which was relatively minor, and because inventories were not a factor in nearly all of the cases where direct business interruption was large (e.g., electricity cannot be stored). It was assumed that hospital inventories would not be significantly affected by most disasters, given the tendency of hospitals to place priority on this feature and to have emergency plans in place to meet shortages. This results in a narrow range in possible inventory holdings.

Combining Sampling Uncertainty and Modeling Uncertainty

Since the total benefit of FEMA grants is uncertain, it is useful to quantify and combine all important sources of uncertainty. This information can then be used to calculate two interesting considerations: (1) a probabilistic range for the total benefit of FEMA grants for each hazard; and (2) the probability that the "true" benefits exceed the cost. The uncertainty in total benefit of FEMA grants results from two principle sources:

1. *Sampling uncertainty*. Total benefits are uncertain because they are estimated from a sample (a subset) of FEMA grants, not the entire population of them. Here, sampling uncertainty is quantified in Table 3, via the sample standard deviation of the benefit-cost ratio.
2. *Modeling uncertainty*. Total benefits are uncertain because a mathematical model of benefits has been created and applied, and that mathematical model has its own uncertain parameters. For this report, modeling uncertainty is quantified in "Sample Results," via the standard deviation of benefit.

As detailed in MMC (2005; Appendix R), these two sources of uncertainty are combined to estimate overall uncertainty in benefit of FEMA grants. The following two observations are made:

1. Modeling uncertainty dominates total uncertainty so a larger sample would not significantly improve the accuracy of the estimated benefits; and
2. The results reaffirm the observation that grants for project mitigation activities produce benefits in excess of costs with high probability for all three hazards.

Conclusions

Congress requested that an independent study determine savings from FEMA-funded mitigation activities. In response, this study determined that the present value discounted net benefits to society from 5,479 FEMA grants between mid-1993 and mid-2003 for flood, wind, and earthquake hazard mitigation is $10.5 billion. The gross benefits are approximately $14.0 billion, and the cost to society is $3.5 billion. The benefit-cost ratios for these grants average 4.0. Thus, Americans benefited greatly from FEMA's investment in mitigation.

The benefits of mitigation include improved public safety. The projects funded by the grants will prevent an estimated 4,699 injuries and 223 deaths over the assumed life of the mitigation activities, which in most cases is 50 years. Also, another part of the study involving mitigation activities in eight communities confirmed the results from the statistical study of individual grants and found that additional benefits also accrue, some of which were not valued in monetary terms (MMC 2005, Chap. 7).

The study results are robust and reliable. They were tested for sensitivity to reasonable analytical variables.

The results of this study have numerous implications, some of which include:

1. Federal investments in mitigation benefit society. Societal benefits of grants made between 1993 and 2003 were four times greater than the cost;
2. The benefits from mitigation grants are greater than just the benefits that can be measured and valued in monetary terms;
3. Both project- and process-type mitigation activities have benefit-cost ratios exceeding 1.0. However, project mitigation activities in many cases would never take place if a process activity had not generated the initial plan or building code that led to implementation;
4. Deeper insight into the cost effectiveness of hazard mitigation project grants could be attained by developing and implementing a formal procedure to assess the performance of buildings and infrastructure after all types of disasters; and
5. Although this study did not specifically assess the combined benefits of mitigation activities across all hazards, the methodology could be adapted to do so. This could help government agencies responsible for providing mitigation to utilize an even more cost-effective all-hazards mitigation strategy.

Acknowledgments

The writers would like to thank the following people for their help in the course of this study: members of the Internal Project Review Team, consisting of William Petak (Chair), David Brookshire, Stephanie King, Dennis Mileti, Doug Plasencia, and Zan Turner; MMC Project Staff headed by Claret Heider; FEMA Mitigation office staff, headed by Maria Vorel; members of the Community Study investigation, headed by Elliott Mittler; and the several consultants, graduate assistants, contributors of data and source materials and other reviewers. A complete list of names can be found in MMC (2005). This research was completed under the auspices of the Multihazard Mitigation Council (MMC) of the National Institute of Building Sciences (NIBS), which was charged by FEMA to conduct the necessary research requested by Congress. In Phase I, MMC (2002) specified the parameters of such a study with two parallel and interrelated components: a nationwide statistical sample to assess the savings realized through mitigation, and a community-based study to examine standard benefits as well as effects of mitigation that might be otherwise be difficult to quantify, such as additional mitigation activities that result from but are not a part of FEMA-funded mitigation. The Applied Technology Council was the contractor chosen to perform the study. The first seven writers listed were assembled by ATC as members of the Project Team to undertake the Benefit-Cost Analysis of FEMA Mitigation Grants using the National Statistical Sample, with Adam Rose as team leader and Keith Porter as coleader. Ron Eguchi served as overall project director, and Tom McLane served as project manager. The last five writers (except Kiremidjian) were among a larger group, cochaired by Dennis Mileti and Brent Woodworth, that carried out the Phase I Study, and, together with L. Thomas Tobin and Kiremidjian, comprised the Project Management Committee that provided valuable input into its implementation in the Phase II Study, part of which is reported upon here.

Table 6. Methods Used to Estimate Benefits for Grants for Project Mitigation Activities

	Hazard			
		Wind		
Benefit type	Earthquake	Hurricane	Tornado	Flood
Property damage	HAZUS MH	HAZUS MH	HAZUS MH reduced form	HAZUS MH reduced form
Business interruption				
Utilities	HAZUS MH extension[a]	HAZUS MH extension[a]	HAZUS MH extension[a]	n.a.[b]
Other	HAZUS MH	HAZUS MH	HAZUS MH	n.a.[b]
Displacement	HAZUS MH[c]	HAZUS MH[c]	HAZUS MH extension[a,c]	HAZUS MH extension[a]
Casualty[d]				
Structural	HAZUS MH	Benefit transfer	HAZUS MH reduced form[e]	Benefit transfer
Nonstructural	Benefit transfer	n.a.[f]	n.a.[f]	n.a.[f]
Environmental and historical	Benefit transfer	Benefit transfer	Benefit transfer	Benefit transfer

Note: A "surrogate benefit" method was used to estimate all benefit categories for process activities (Section 4.3.5 and Appendix K).

[a] Extension refers to a method that builds on HAZUS MH with a similar and compatible approach.

[b] None of the sampled flood projects involved business interruption.

[c] Measured as part of business interruption.

[d] Also includes emergency services benefits.

[e] Reduced form refers to the use of component parts, such as functional relationships and data, from a HAZUS MH module.

[f] Only relevant to earthquakes.

Appendix I. Benefit Estimation Methods

Overview

Table 6 summarizes the methods used for each hazard and benefit type (avoided loss). HAZUS MH, in various forms, was the predominant method. "HAZUS MH extension" refers to methods developed expressly for this study to fill in a gap in the tool (e.g., its application to determining the full range of direct business interruption losses from lifeline failures as well as indirect business interruption losses). "HAZUS MH reduced form" refers to the use of various data and functional relationships from HAZUS MH (e.g., data and damage functions relating to flooding). More details of these adaptations of HAZUS MH can be found in the appendices of MMC (2005).

HAZUS MH

HAZUS MH is built on an integrated GIS platform that estimates losses due to earthquake, flood, and hurricanes. The software program is composed of seven major interdependent modules. The connectivity between the modules is conceptualized by the flow diagram in Fig. 5. The following discussion provides a brief description of each module; detailed technical descriptions can be found in the *HAZUS MH technical manuals* (NIBS and FEMA 2003a, c, 2003b).

Potential Hazards (1)

The potential-hazards module estimates the expected intensities or hazard severities for three hazards: earthquake, flood, and hurricane. For earthquake, this would entail the estimation of ground motions and ground failure potential from landslides, liquefaction, and surface fault rupture. For flood, this involves the estimation of flood heights or depths. For hurricane, this entails the estimation of wind speeds. For a probabilistic analysis, the added element of frequency or probability of occurrence would be included.

Inventory Data (2)

A national-level exposure database is built into HAZUS MH, which allows the user to run a preliminary analysis without having to collect additional local information or data. The default database includes information on the general building stock, essential facilities, transportation systems, and utilities. The general building stock data are classified by occupancy (residential, commercial, industrial, etc.) and by model building type (structural system, material of construction, roof type, and height). The default mapping schemes are state-specific for single-family dwellings and region-specific for all other occupancy types. In all cases, they are age and building-height specific.

Direct Damage (3)

This module estimates property damage for each of the four inventory groups (general building stock, essential facilities, transportation, and utilities), based on the level of exposure and the vulnerability of structures at different hazard intensity levels.

Induced Damage (4)

Induced damage is defined as the secondary consequence of a disaster event on property. Fire following an earthquake and accumulation of debris are examples.

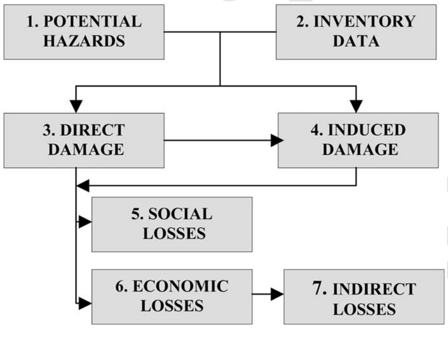

Fig. 5. HAZUS MH modules

Societal Losses (5)

Societal losses are estimated in terms of casualties, displaced households, and short-term shelter needs. The casualty model provides estimates for four levels of casualties (minor injuries to deaths), for three times of day (2:00 a.m., 2:00 p.m., and 5:00 p.m.), and for four population groups (residential, commercial, industrial, and commuting). The number of displaced households is estimated based on the number of structures that are uninhabitable, which is in turn estimated by combining damage to the residential building stock with utility service outage relationships.

Economic Losses (6)

Direct economic losses are estimated in terms of structural and nonstructural damage, contents damage, costs of relocation, losses to business inventory, capital-related losses, wage and salary income losses, and rental losses.

Indirect Economic Losses (7)

This module evaluates region-wide ("ripple") and longer-term effects on the regional economy from earthquake, flood, and wind losses. Estimates provided include changes in sales, income, and employment, by industrial sector.

The various modules of the HAZUS MH software have been calibrated using existing literature and damage data from past events. For earthquake, two pilot studies were conducted several years ago for Boston and Portland, Ore., to further assess and validate the credibility of estimated losses. A similar testing and validation effort was conducted for flood and hurricane wind.

Appendix II. Assumptions

Following are the most significant assumptions of our analysis. They were necessitated by a combination of standard practices, data limitations, and computational manageability.

1. *Risk neutrality*. This is a standard assumption of benefit-cost analysis;
2. *Meaning of benefits and costs*. Benefits were taken as the present value of reduced future losses. Costs were taken as the expected present value of the cost to undertake a mitigation measure. Some categories were ignored, such as facility operation and maintenance costs. Intangible (nonmarket) costs of mitigation could not be quantified;
3. *Implementation effectiveness*. We assume that each mitigation activity is fully implemented at maximum effectiveness;
4. *Accuracy of HAZUS MH*. While its accuracy remains to be fully proven, HAZUS MH represents the only available national standard multihazard loss-estimation tool. The complete HAZUS MH flood loss module was not ready for use, although its damage functions were used;
5. *HAZUS MH default values*. Several were used, most notably, relocation costs, repair duration, building recovery time, rental income, and recapture factor, import and export capability, restoration of function, rebuilding pattern, and inventory demand and supply;
6. *Time value of money*. Future economic values were brought to present value at time-constant discount rates of 2%, and results were sensitivity tested to discount rates between 0 and 7%;
7. *Inflation adjustment*. All dollar values of past costs were adjusted to January 1, 2002, terms using the consumer price index;
8. *Planning period*. Property mitigations were assumed to be effective for 50 years for ordinary structures and 100 years for important structures and infrastructure, regardless of property age;
9. *Accuracy of FEMA data*. Data in the NEMIS and grant applications were assumed to be correct, subject to some limited quality control;
10. *Accurate soil data*. U.S. Geological Survey and California Geologic Survey soil maps were assumed to be accurate;
11. *Value of avoided statistical deaths and injuries*. Avoided statistical deaths and injuries were valued using FHwA (1994) figures, brought to 2002 constant dollars, but not time discounted;
12. *Constant hazard*. Hazard levels were assumed to be time invariant;
13. *Direct business interruption*. These losses were not applied to residences;
14. *Indirect business interruption*. These losses were not applied to residences, schools, libraries, hospitals, and fire houses;
15. *Excess capacity*. The unemployment rate was used as a proxy;
16. *Boundaries of regional economies for indirect business interruption loss estimation*. Regional economies were delineated by the boundaries of the county or county group incurring physical damage, although most economic regions, or trading areas, do not conform precisely to political boundaries;
17. *Regional input-output (I-O) tables*. The HAZUS MH I-O algorithm is superior to standard I-O formulations, but retains the limitations of the lack of input substitution and the absence of the explicit role of prices; and
18. *No interaction between grants*. The analysis assumed no interaction between mitigation efforts.

References

Bernknopf, R. L., Brookshire, D., McKee, M., and Soller, R. (1997). "Estimating the social value of geologic map information: A regulatory approach." *J. Envir. Econom. Manage.*, 32, 204–218.

Boardman, A., Greenberg, D., Vining, A., and Weimer, D. (2001). *Cost benefit analysis: Concepts and practice*, 2nd Ed., Prentice-Hall, Englewood Cliffs, N.J.

Brookshire, D., and Neil, H. (1992). "Benefit transfers: Conceptual and empirical issues." *Water Resour. Res.*, 28, 651–655.

Canaan, D. (2000). "Charlotte-Mecklenburg's floodplain mapping data and decisions." *Research in Support of Hazard Mitigation, Symp. Proc.*, North Carolina Division of Emergency Management, Raleigh, N.C.

Cowen, T., and Parfit, D. (1992). "Against the social discount rate." *Justice across the generations: Philosophy, politics, and society*, P. Laslett and J. Fishkin, eds., Yale University Press, New Haven, Conn.

Farber, D., and Hemmersbaugh, P. (1993). "The shadow of the future: Discount rates, later generations, and the environment." *Vanderbilt Law Review*, 46, 267–304.

Federal Emergency Management Agency (FEMA). (2005). "Detailed expenditure data, 1993–2003." Computer file, Washington, D.C.

Federal Highway Administration (FHwA). (1994). "Technical advisory: Motor vehicle accident cost." *Technical Advisory No. 7570.2*, U.S. Department of Transportation, Washington, D.C.

Ganderton, P. (2005). "Benefit-cost analysis of hazard mitigation: The current state of what counts and how to count it." *Mitigation and Adaptation Strategies for Global Change*, 10, 445–65.

Golan, E., et al. (2000). "Economics of food labeling." *Rep. No. 793*, U.S. Department of Agriculture, Economic Research Service, Washington, D.C.

Julier, S. J., and Uhlmann, J. K. (2002). "Reduced sigma point filters for the propagation of means and covariances through nonlinear transformations." *Proc. American Control Conf.*, Anchorage, Alaska.

Litan, R., Krimgold, F., Clark, K., and Khadilkar, J. (1992). *Physical damage and human loss: The economic impact of earthquake mitigation measures*, Insurance Information Institute Press, New York.

Lombard, P. (1995). "Economics of building code benefits pertaining to specific structural and property changes or impacts from hurricane-forced winds." Ph.D. dissertation, Texas A&M Univ., College Station, Tex.

Multihazard Mitigation Council (MMC). (2002). "Parameters for an independent study to assess the future benefits of hazard mitigation activities." *Rep. Prepared by the Panel on Assessment of Savings from Mitigation Activities*, Multihazard Mitigation Council/National Institute of Building Sciences, Washington, D.C.

Multihazard Mitigation Council (MMC). (2005). "Natural hazard mitigation saves: Independent study to assess the future benefits of hazard mitigation activities." *Study documentation*, Vol. 2, Federal Emergency Management Agency of the U.S. Department of Homeland Security by the Applied Technology Council under contract to the Multihazard Mitigation Council of the National Institute of Building Sciences, Washington, D.C.

National Institute of Building Sciences (NIBS) and Federal Emergency Management Agency (FEMA). (2003a). *Multihazard loss estimation methodology, earthquake model, HAZUS MH technical manual*, Washington, D.C.

National Institute of Building Sciences (NIBS) and Federal Emergency Management Agency (FEMA). (2003b). *Multihazard loss estimation methodology, flood model, HAZUS MH technical manual*, Washington, D.C.

National Institute of Building Sciences (NIBS) and Federal Emergency Management Agency (FEMA). (2003c). *Multihazard loss estimation methodology, hurricane model, HAZUS MH technical manual*, Washington, D.C.

Porter, K. (2002). "Life-safety risk criteria and seismic decisions." *Acceptable risk processes: Lifelines and natural hazard*, C. Taylor and E. VanMarcke, eds., American Society of Civil Engineers, Reston, Va.

Porter, K. A., Scawthorn, C. R., and Beck, J. L. (2006). "Cost-effectiveness of stronger woodframe buildings." *Earthquake Spectra*, 22(1), 239–266, ⟨http://keithp.caltech.edu/Porter-2006-woodframe.pdf⟩.

Rose, A. (2004a). "Defining and measuring economic resilience to disasters." *Disaster Prevention and Manage.*, 13(4), 307–314.

Rose, A. (2004b). "Economic principles, issues, and research priorities in natural hazard loss estimation." *Modeling the spatial economic impacts of natural hazards*, Y. Okuyama and S. Chang, eds., Springer, Heidelberg, Germany, 13–36.

Rose, A., Benavides, J., Chang, S., Szczesniak, P., and Lim, D. (1997). "The regional economic impact of an earthquake: Direct and indirect effects of electricity lifeline disruptions." *J. Regional Sci.*, 37, 437–458.

Rose, A., and Kverndokk, S. (l999). "Equity and environmental policy." *Handbook of environmental and resource economics*, J. van den Bergh, ed., Edward Elgar Publishers, Cheltenham, U.K., 352–379.

Taylor, C., Porush, A., Tillman, C., Reaveley, L., and Blackham, G. (1991). *Seismic code decisions under risk*, Dames & Moore, National Science Foundation, Los Angeles.

"Treasury quotes." (2003). *Wall Street Journal Online*, September, 12, 2003.

URS Group, Inc. (2001). "A report on the cost-effectiveness of the TriNet project." *Final Rep. to the Federal Emergency Management Agency*, Washington, D.C.

U.S. Senate. (1999). "Departments of Veterans Affairs and Housing and Urban Development, and Independent Agencies Appropriations Bill, 2000." *Senate Rep. No. 106–161*, Washington D.C., ⟨http://thomas.loc.gov/cgi-bin/cpquery/T?report=sr161&dbname=106&⟩.

Van Der Pol, M, and Cairns, J. (2000). "Negative and zero time preference for health." *Health Econ*, 9(2), 171–175.

Zerbe, R., and Dively, D. (1994). *Benefit-cost analysis in theory and practice*, HarperCollins, New York.