Benefit-Cost Analysis of FEMA Hazard Mitigation Grants

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Abstract

Mitigation ameliorates the impact of natural hazards on communities by reducing loss of life and injury, property and environmental damage, and social and economic disruption. The potential to reduce 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) can be used 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 refined BCA methodologies and applied them to a national statistical sample of FEMA mitigation activities over a ten-year period for earthquake, flood, and wind hazards. The results indicate that the overall benefit-cost ratio for FEMA mitigation grants is about 4 to 1, though the ratio varies according to hazard and mitigation type.

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I. INTRODUCTION

A. 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, 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 matching funds have been spent to address floods, windstorms, and earthquakes. 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 mitigation activities (U.S. Senate, 1999).[1] This paper summarizes the results of applying BCA to a nationwide statistical sample of FEMA-funded mitigation activities.

B. 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; Chs. 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, for a total of six strata.[2] Specific methods and data used in the estimation of each stratum are also identified.

Because this was a statistical analysis, the emphasis was placed on major statistical indicators applicable to an entire stratum — the mean benefit and its standard deviation — rather than on benefits from individual grants or subcategories of mitigation activity such as purchase and demolition of property in floodplains, base isolation of seismically vulnerable buildings, etc. Explanations are offered for statistical outliers (extreme values) and for those cases where the results are unusual or counterintuitive.

BCRs were calculated for a statistical sample of each stratum and extrapolated to the population of all FEMA hazard mitigation grants. 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 and informal evaluations of methodological limitations and assumptions. The total national benefits of FEMA hazard mitigation grants between mid-1993 and mid-2003 are $14.0 billion compared with $3.5 billion in costs. This yielded an overall benefit-cost ratio of 4.0. Thus, every dollar spent on a FEMA hazard mitigation grant produced, on average, four dollars of benefits—a sizable return on public dollar expenditures.

II. 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 given 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 report are:

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 (non-market) 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 A, and more details of its application are presented during the course of the discussion below.

Not all mitigation measures 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 Neill, 1992; Bergstrom and DeCivita, 1999). The approach was developed for situations in which the time or money costs of primary data collection are prohibitive. In this approach, benefit estimates from other case studies are spatially or temporally transferred to the policy case study.

Several assumptions underlie the analysis. Here we note the major ones and refer the reader to the Appendix B for others. We assumed time-constant discount rates of 2%. (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, but not time discounted. All dollar values were adjusted to January 1, 2002, terms using the Consumer Price Index.

III. 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 later; 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.[3] 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 cross-checked by a review of the grant application.

Grant data were acquired in electronic format for 5,479 approved or completed grants to mitigate flood, earthquake, or wind. 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. The study investigators collected additional data on as many of these grants as possible (see MMC, 2005; Ch. 3).

A rigorous random sampling technique was applied to select these 357 grants (see MMC, 2005; Ch. 4 for details). The sample grants were selected to 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. 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.

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, elevating, or relocating buildings, lifelines or other structures threatened by floods; strengthening buildings and lifelines or their components to resist earthquake or wind forces; and 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 set priorities; educating decision-makers, and building constituencies; and facilitating the selection, design, funding, and construction of projects.[4]

IV. Sample Results

A. Sampled Grants for Project Mitigation Activities

This section summarizes results for grants for *project* mitigation activities only for earthquake, wind, and flood. Section IV.B 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 Appendix Table A.

1. 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.

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

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.[5] 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.

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.[6]) In addition, an inherent assumption of the HAZUS®MH methodology is that only *structural* mitigation results in business interruption benefits.[7] 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, 2004b). Business interruption benefits contribute about 10 percent 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 percent 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, 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 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 percent of the total benefits in the earthquake project grant stratum.[8]

For this stratum (as well as for the others below), the overall approach has leaned toward conservatism. 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.

2. 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.[9]

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 4 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 to 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.[10]

3. 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; Ch. 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 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 million 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.

B. 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 the "surrogate benefit" approach.[11]

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

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

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

1. 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.

2. 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.

3. 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.

4. 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; Ch. 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 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 to 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 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. Third, blanket categorical benefit-cost ratios are unwise. 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; Ch. 5).

V. Extrapolation of Sample Results to Population

The results presented in previous sections were scaled to the population of grants using the arithmetic mean approach. These population totals are presented in Table 2 for project and process grants. The results indicate 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 3 summarizes the calculation of stratum benefit-cost ratio. 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.

Table 2. Mitigation Benefits and Sample Size by Hazard (in 2004 dollars)

		Population		Sample	
Hazard	**Type**	**Count**	**Benefits ($M)**	**Count**	**Benefits ($M)[1]**
Wind	Project	1,190	1,307	42	219
	Process	382	161	21	44
Flood	Project	3,404	11,172	22	388
	Process	108	17	6	2
Earthquake	Project	347	1,194	25	365
	Process	48	198	20	93
Total		5,479	14,049	136	1,111

[1]The reader should *not* expect that (stratum sample benefit) = (stratum sample cost) x (stratum average BCR), because of the sampling and scale-up strategy. Stratum BCR is taken as $1/n*\Sigma(BCR_i)$, where BCR_i = (sample i benefit)/(sample i cost), and n = count of grants in the stratum sample. The BCR for each grant in the stratum sample is weighted equally. Grants are sampled from the population so that more-costly grants are more likely to be selected for sampling, with likelihood of being selected for the sample approximately proportional to cost. This procedure for sampling grants and scaling up to the population was found to produce lower error and lower uncertainty than randomly sampling grants from the stratum with equal probability, summing their benefits, summing their costs, and taking the resulting ratio as the estimate of the population's BCR for that stratum. Furthermore, it should *not* be expected that (total population benefit)/(total population cost) = (total sample benefit)/(total sample cost), because of the sampling and scale-up technique.

Table 3. Scale-Up of Results to all FEMA Grants (all $ figures in 2004 constant dollars)

	Project Grants			Process Grants			
	Quake	**Wind**	**Flood**	**Quake**	**Wind**	**Flood**	**Total**
Total grant cost ($M)	$ 867	$ 280	$ 2,204	$ 80	$ 94	$ 13	$ 3,538
Total 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
Standard deviation of BCR	1.3	7.0	1.1	n.a.	n.a.	n.a.	n.a.

*Row 2 (benefit) divided by row 1 (cost) equals row 3 (benefit-cost ratio)

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

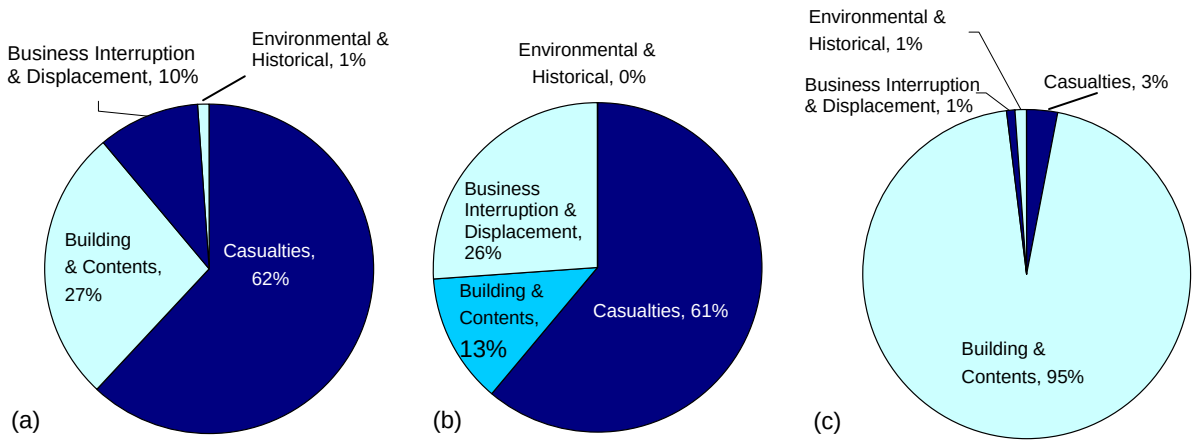

Figure 1. Contribution to Benefit-Cost Ratio by Factor for: (a) Earthquake, (b) Wind, and (c) Flood.

Table 4. 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

Table 5. 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

As shown in Figure 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.

A. Breakdown of Results

The results are summarized by grants for each hazard type in Table 4, which shows that overall, mitigation grants for each hazard has a benefit-cost ratio greater than one, with the grants for flood mitigation being the most cost-beneficial (BCR = 5.0). Table 5 also 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 percent of the total FEMA grant benefits. Wind and earthquake benefits each represent approximately 10 percent of the total.

In assessing the results, recall that grants for process activities (including Project Impact) represent only 10 percent of the total number of FEMA grants in the NEMIS database (the total population). Moreover, they represent only about 5 percent of the total FEMA grant expenditures nationwide. As shown in Table 5, process grant benefits represent 2.7 percent 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.

B. Deaths and Injuries

Table 6 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 population data, scale-up requires estimates based on proportional grant costs. The ratio of sample grant injury reduction to sample grant costs was applied to population costs to estimate national reduction by stratum.

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 6, 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.

Table 6. 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

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.

C. 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.

D. 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 percent of flood benefits are attributable to avoided losses to structures and contents, and only three percent is for casualty reduction, as opposed to casualty reductions slightly over 60 percent 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 due in part to 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.[12] 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.

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 percent of total flood project mitigation benefits, in contrast to 1.2 percent 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 non-structural 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 a hundred years.

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 earthquake zones (as well as the idiosyncratic nature of an earthquake project grant in our sample oriented toward life safety). However, *potential* BCRs 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.

VI. Sensitivity Analysis

Sensitivity analyses were performed on key parameters of our analysis. Figures 2-4 illustrate how making different assumptions affects the total estimated benefit for those that revealed the greatest range of sensitivities. 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.

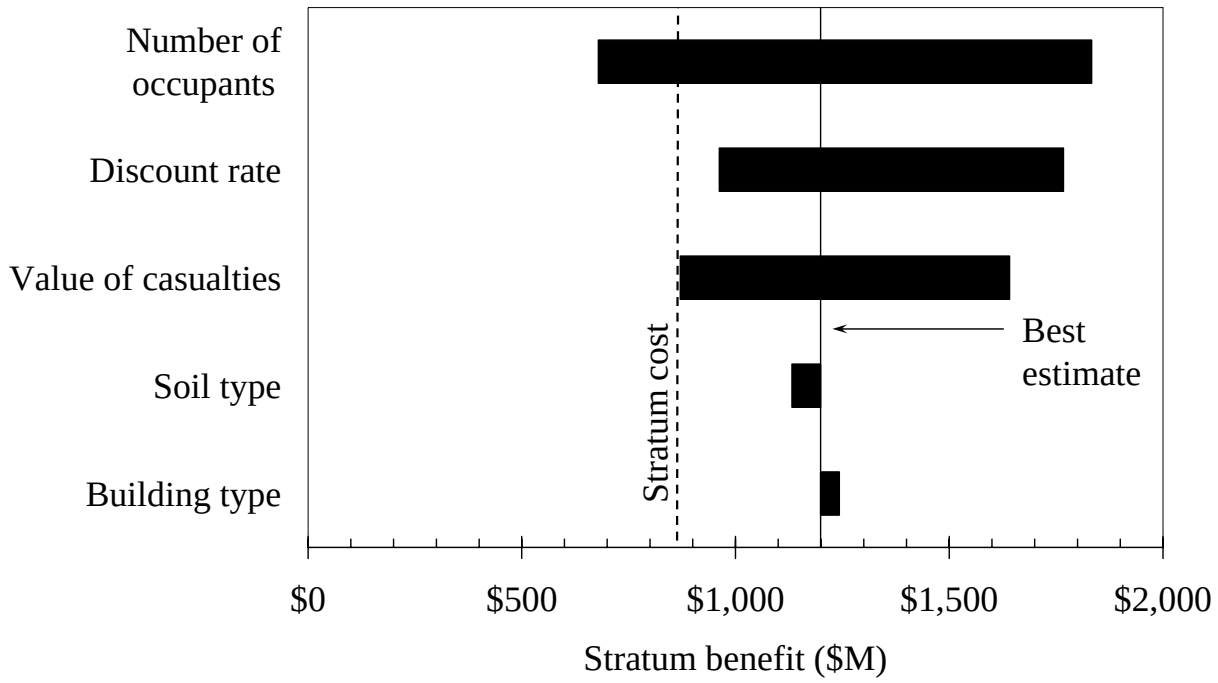

Figure 2. Sensitivity of Benefit to Uncertainties (grants for earthquake project mitigation activities)

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. 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. 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 was used called an "unscented transform"[13] (Julier and Uhlman, 2002). Using this procedure, it was possible to estimate the probability that the "true" total nationwide benefit for a given hazard exceeds the cost. The unscented transform makes it unnecessary to vary several parameters simultaneously; it accounts for the probability that several parameters will be greater or less than their best-estimate values.

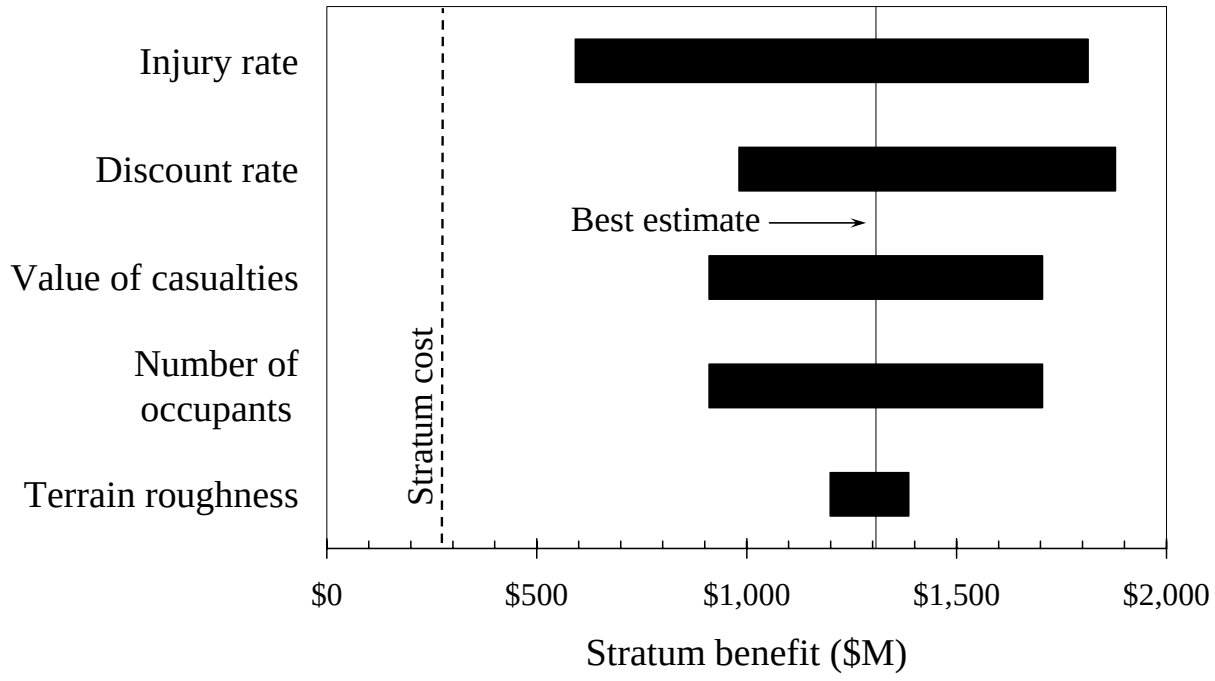

Figure 3. Sensitivity of Benefit to Uncertainties (grants for wind project mitigation activities)

A. Basic Results

1. Grants for Earthquake Project Activities

Results for earthquake project mitigation benefits are illustrated in Figure 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 standard deviation bounds of benefit are $850 million and $1.7 billion. Benefit exceeds cost with 83 percent 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 $1.50 in reduced future losses for every $1 spent.

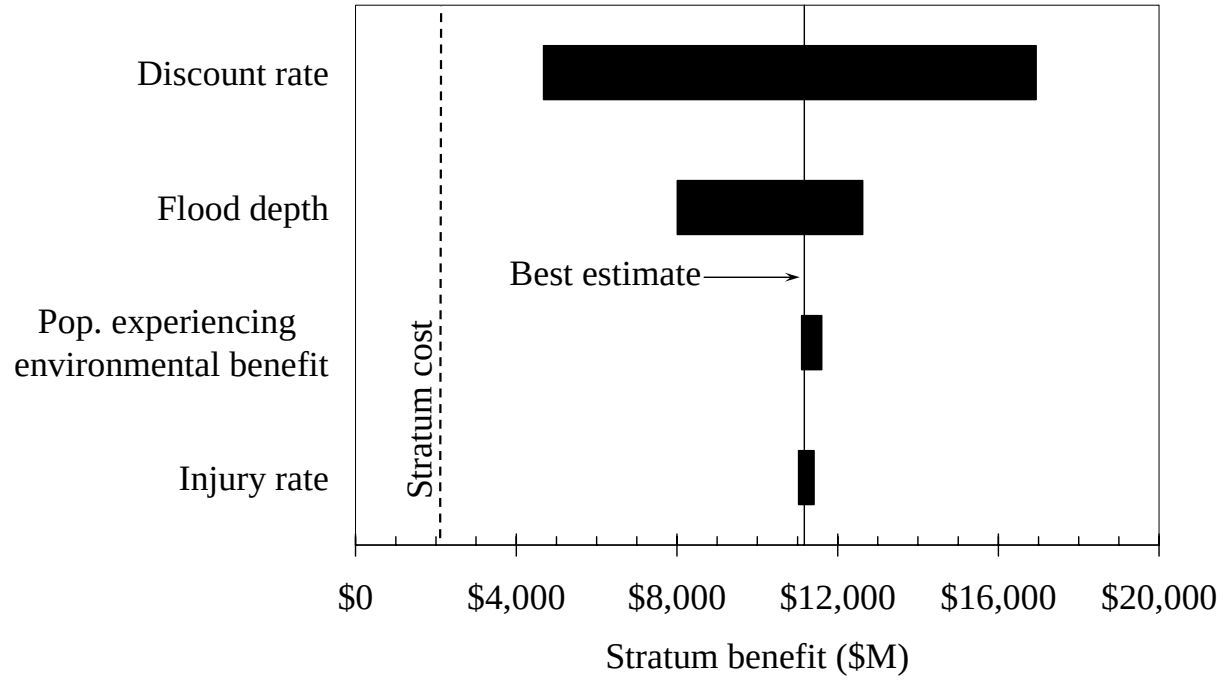

Figure 4. Sensitivity of Benefit to Uncertainties (grants for flood project mitigation activities)

2. Grants for Wind Project Mitigation Activities

Figure 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 standard deviation bounds of benefit are $800 million and $1.8 billion. There is greater than 99 percent 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.

3. Grants for Flood Project Mitigation Activities

Figure 4 shows the diagram for grants for flood project mitigation activities. Flood project benefits are most 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 standard deviation bounds of benefit are $7 billion and $15 billion. There is greater than 99 percent 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.

B. 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 to disasters factored into this study (recall the discussion in Section IVA). 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.

VII. 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 parameters: 1) confidence bounds for the total benefit of FEMA grants for each hazard, and 2) the probability that the "true" benefits exceed the cost. "Confidence bounds" refers to upper and lower bounds between which the "true" total benefit lies with any given level of probability. 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 standard deviation of 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 Section V, via the standard deviation of benefit.

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

1. Modeling uncertainty dominates total uncertainty so a larger sample would not improve the accuracy of the estimated benefits.
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.

VIII. 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 grants FEMA mitigation 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.

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:

- Federal investments in mitigation benefit society. Societal benefits of grants made between 1993 and 2003 were four times greater than the cost;
- The benefits from mitigation grants are greater than just the benefits that can be measured and valued in monetary terms;
- 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.
- 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.
- 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.

ENDNOTES

[*] The authors 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 investigators, headed by Elliott Mittler; and the several consultants, graduate assistants, and contributors of data and source materials.

[1] FEMA in turn charged the Multihazard Mitigation Council (MMC) of the National Institute of Building Sciences (NIBS) with the conduct of the necessary research. In Phase I, MMC specified the parameters of such a study (MMC 2002) 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 authors 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 Co-Leader. Ron Eguchi served as overall Project Director, and Tom McLane served as Project Manager. The last five authors (except Kiremidjian) were among a larger group, co-chaired by Dennis Mileti and Brent Woodworth, that carried out the Phase I Study, and, together with L. Thomas Tobin, comprised the Project Management Committee that provided valuable input into its implementation in the Phase II Study, part of which is reported upon here.

[2] The results for a third category of grants, Project Impact grants, are presented in MMC, 2005; Ch. 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.

[3] During the period studied, FEMA conducted three programs in support of hazard mitigation: the post-disaster Hazard Mitigation Grant Program (HMGP) and two pre-disaster 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 obligated $3.5 billion for states and communities to invest in a variety of eligible 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 pre-disaster mitigation programs. In total, 250 communities across all states and some U.S. 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 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.

[4] See MMC, 2005; Ch. 2 for a more extensive discussion of the distinction between project and process grants.

[5] Independent estimates of the costs of administering FEMA grants could not be obtained, so this portion of the costs was omitted. Since mitigation is likely to lead to near comparable reductions in the need to incur this administrative costs, this means administrative costs and benefits are likely to come close to offsetting each other.

[6] 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).

[7] For the earthquake and wind project strata, business interruption also included the costs of displacement effects. For the case of buyouts of flood-prone residences, these effects were calculated separately.

[8] 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.

[9] 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. 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 standard deviations), 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 percent significance level.

[10] 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 one when casualty rates were reduced an order of magnitude lower than the estimated rates. If only 10 percent 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.

[11] 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 (e.g., radon risk communication) were used instead. Hence, this modified application is referred to as a *surrogate* benefit approach.

[12] For example, mitigation grants to replace pendant lighting in schools provided potential protection but did not always yield actual benefits, as in the cases of the Northridge and Loma Prieta earthquakes, which took place when schools were not in session.

[13] An unscented transform is a mathematical technique for selecting samples of set of uncertain variables, to estimate the mean value, variance, and other statistics of a function of those variables. The technique is far more efficient than random sampling (such as by Monte Carlo simulation), meaning that far few samples are required using the unscented transform than using random sampling to achieve the same level of accuracy.

APPENDIX A. BENEFIT ESTIMATION METHODS

A. Overview

Table A 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).

Table A. Methods Used to Estimate Benefits for Grants for Project Mitigation Activities[1]

	Hazard			
	Earthquake	**Wind**		**Flood**
Benefit Type		**Hurricane**	**Tornado**	
Property Damage	HAZUS®MH	HAZUS®MH	HAZUS®MH Reduced Form	HAZUS®MH Reduced Form
Business Interruption				
Utilities	HAZUS®MH Extension[2]	HAZUS®MH Extension[2]	HAZUS®MH Extension[2]	n.a.[3]
Other	HAZUS®MH	HAZUS®MH	HAZUS®MH	n.a.[3]
Displacement	HAZUS®MH[4]	HAZUS®MH[4]	HAZUS®MH Extension [2,4]	HAZUS®MH Extension[2]
Casualty[5]				
Structural	HAZUS®MH	Benefit Transfer	HAZUS®MH Reduced Form[6]	Benefit Transfer
Nonstructural	Benefit Transfer	n.a.[7]	n.a.[7]	n.a.[7]
Environmental and Historical	Benefit Transfer	Benefit Transfer	Benefit Transfer)	Benefit Transfer

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

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

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

[4]Measured as part of business interruption.

[5]Also includes emergency services benefits.

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

[7]Only relevant to earthquakes.

B. 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 Figure A. 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, 2003b, 2003c).

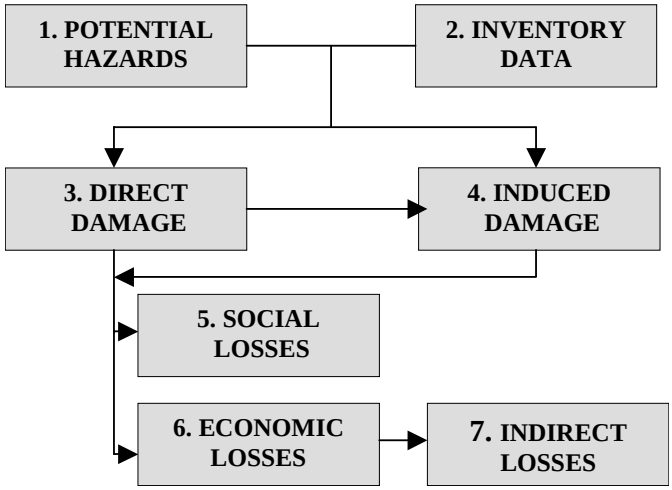

Figure A. HAZUS®MH Modules

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.

Social 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, Massachusetts, and Portland, Oregon, to further assess and validate the credibility of estimated losses. A similar testing and validation effort was conducted for flood and hurricane wind.

APPENDIX B. ASSUMPTIONS

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

Risk neutrality. This is a standard assumption of benefit-cost analysis.

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.

Accuracy of HAZUS®MH. While its accuracy remains to be fully proven, HAZUS®MH represents the only available national standard multi-hazard loss-estimation tool. The complete HAZUS®MH flood loss module was not ready for use, although its damage functions were used.

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.

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%.

Inflation adjustment. All dollar values were adjusted to January 1, 2002, terms using the Consumer Price Index.

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.

Accuracy of FEMA data. Data in the National Emergency Management Information System (NEMIS) and grant applications were assumed to be correct, subject to some limited quality control.

Accurate soil data. U.S. Geological Survey and California Geologic Survey soil maps were assumed to be accurate.

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.

Constant hazard. Hazard levels were assumed to be time-invariant.

Direct business interruption. These losses were not applied to residences.

Indirect business interruption. These losses were not applied to residences, schools, libraries, hospitals, and fire houses.

Excess capacity. The unemployment rate was used as a proxy.

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.

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.

No interaction between grants. The analysis assumed no interaction between mitigation efforts.

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