Chapter 6
BENEFIT-COST ANALYSIS OF FEMA MITIGATION GRANTS

The results of the benefit-cost analysis of FEMA mitigation grants are presented and explained below. These results are based on the data and methods summarized in Chapters 3 and 4. Results are presented for two major categories of grants ─ those for project activities and those for process activities; and for three hazards ─ earthquake, flood, and wind.[62] Classification thus resulted in six strata. 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 individual grants. Explanations are offered for statistical outliers (extreme values) and for those cases where the results are unusual or counterintuitive.

Overall, the benefit-cost analysis of FEMA mitigation grants found that the benefit-cost ratio of all strata were greater than 1.0. Moreover, this result is robust to formal sensitivity tests and informal evaluations of methodological limitations and assumptions.

The sample results also were extrapolated to the population totals. 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. This means that the benefits of these grants to the nation significantly exceed their costs.

In addition, the savings to the federal treasury were estimated. Federal expenditures on hazard mitigation were juxtaposed against potential savings in federal post-disaster recovery expenditures and recouped federal taxes. The results were that every dollar of hazard mitigation expenditures potentially saves the federal treasury $3.65 of future discounted expenditures or lost taxes. Thus, in addition to providing broad-based benefits to society, the FEMA hazard mitigation grant programs more than pay for themselves.

6.1 Project Selection

This study addresses all FEMA-funded mitigation grants that satisfy the following criteria: (1) the grant was listed in the NEMIS database provided by FEMA in July, 2003; (2) the grant was associated with presidentially declared 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 (including both hurricanes and tornadoes) as determined using FEMA's coding for project type. 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.

[62] The results for a third category of grants, Project Impact grants, are presented in Chapter 5.

6.2 Stratified Sample

Project 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 examination. Each combination of mitigation type (project or process) and hazard represents one stratum. The study investigators collected additional data on as many of these grants as possible (see Section 3.2.2 for discussion of this process).

A rigorous random sampling technique was applied to select these 357 grants (see Section 4.5.1 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. 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. Many of the 312 grant application files contained insufficient data to estimate benefits of mitigation, and a few produced results that caused investigators to exclude them from the final sample (these "outliers" are discussed later). Eventually, 136 grant applications remained in the sample.

Table 6-1 summarizes the distribution of these grants by mitigation type and hazard for the entire population of grants that satisfy the criteria listed in Section 6.1 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 such as structural retrofit) from activities involving support functions (process mitigation activities such as public awareness campaigns or research).

Table 6-1 Distribution of grants by mitigation type and 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

6.3 Sample Results

6.3.1 Sampled Grants for Project Mitigation Activities

This section covers grants for project mitigation activities only for earthquake, wind, and flood. Section 6.3.2 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 6-2. Table 6-2 also includes the section of this report in which a detailed explanation of the method is found.

6.3.1.1 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 sample 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 casualties. 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 (see discussion in Section 4.3). These avoided losses included business interruption impacts associated with utility outages, damage to pendant lighting and ceilings, environmental/historical benefits and some societal benefits (see Appendices C through K). Section 2.1.1 discusses the fact that independent estimates of the costs of administering FEMA grants could not be obtained.

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.

Table 6-2 Methods used to estimate benefits for grants for project mitigation activities[1]

	Hazard			
	Earthquake	Wind		Flood
Benefit Type		Hurricane	Tornado	
Property Damage	HAZUS®MH (Section 4.2.1)	HAZUS®MH (Section 4.2.1)	HAZUS®MH Reduced Form (Appendix H)	HAZUS®MH Reduced Form (Appendix G)
Business Interruption				
Utilities	HAZUS®MH Extension[2] (Appendix I)	HAZUS®MH Extension[2] (Appendix I)	HAZUS®MH Extension[2] (Appendix I)	n.a.[3]
Other	HAZUS®MH (Sec 4.2.2, 4.2.3)	HAZUS®MH (Sec 4.2.2, 4.2.3)	HAZUS®MH (Sec 4.2.2, 4.2.3)	n.a.[3]
Displacement	HAZUS®MH[4] (Sec 4.2.2)	HAZUS®MH[4] (Sec 4.2.2)	HAZUS®MH Extension [2,4] (Sec 4.2.2)	HAZUS®MH Extension[2] (Sec 4.2.3.3)
Casualty[5]				
Structural	HAZUS®MH (Appendix E)	Benefit Transfer (Appendix E)	HAZUS®MH Reduced Form[6] (Appendix E)	Benefit Transfer (Appendix E)
Nonstructural	Benefit Transfer (Appendix E)	n.a.[7]	n.a.[7]	n.a.[7]
Environmental and Historical	Benefit Transfer (Sec 4.3.4; Appendix J)	Benefit Transfer (Sec 4.3.4; Appendix J)	Benefit Transfer (Sec 4.3.4; Appendix J)	Benefit Transfer (Sec 4.3.4; Appendix J)

[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.

HAZUS®MH was used to estimate property damage avoidance (benefits) due to the structural upgrades. These benefits can be significant, with property loss reductions measuring between a few percent and 3.9 times the cost of the retrofit. 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 public buildings such as police and fire departments, civic arenas, and schools.[63]) In addition, an inherent assumption of the HAZUS®MH methodology is that only structural mitigation results in business interruption benefits.[64] The vast majority of nonstructural mitigation measures in this stratum are for pendant lighting in schools, and is 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. 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 is expected, which translates into $131.3 million. The mean 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.

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.[65]

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.

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[63] 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).

[64] 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.

[65] 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.

Box 1 provides an example of where HAZUS®MH was used to calculate the benefits of mitigation for an earthquake-related project grant. Some calculations (i.e., the assessment of indirect economic benefits) were completed outside of HAZUS®MH, and these are clearly identified in the example.

6.3.1.2 Grants for Wind Project Mitigation Activities

Although several mitigation measures are included in the sample grants for the wind project grant stratum, the majority are 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 (see Table 6-2). 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.[66]

Several of the grants that had large benefit-cost ratios (>10.0), including all four outliers that exceeded 50.0, 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.

[66] 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 log normally distributed, passing a Kolmogorov-Smirnov goodness-of-fit test at the 5 percent significance level.

Box 1 HAZUS®MH EXAMPLE - Earthquake

Background

This is an example of where HAZUS®MH was used to calculate expected annual losses from earthquake with and without a mitigation activity. What is illustrated in this example are the input and output of HAZUS®MH and what calculations were done outside of HAZUS®MH to estimate the benefit-cost ratio associated with this mitigation activity. For this example, structural retrofit measures were implemented to improve the overall seismic resistance of a hospital.

HAZUS®MH Basic Input Information

Building Characteristics	Original Building	Retrofitted Building
Occupancy	Hospital	Hospital
Building Type	Concrete Shear-walls	Concrete Shear-walls
Design Level	Low	High
Building Quality	Inferior	Code

HAZUS®MH Models

Damage (median displacement for onset of damage, in inches)	Original Building	Retrofitted Building
Slight	0.96	1.2
Moderate	1.83	3
Extensive	4.74	9
Complete	12	24

Functional Loss		
None (Days)	0	0
Slight (Days)	2	2
Moderate (Days)	68	68
Extensive (Days)	270	270
Complete (Days)	360	360

Recovery Time		
None (Days)	0	0
Slight (Days)	20	20
Moderate (Days)	135	135
Extensive (Days)	540	540
Complete (Days)	720	720

Economic Factors		
Recapture Factor/Business Income	0.6	0.6
Recapture Factor/Wages	0.6	0.6

HAZUS®MH Iutput

Return Period	Peak Ground Acceleration (g)
100 Year	0.20
500 Year	0.38
1000 Year	0.50
2500 Year	0.66

Annualized Losses	Original Building	Retrofitted Building
Building Capital Loss	$235,608	$74,860
Direct Business Interruption Loss	$412,968	$69,083
SUBTOTAL ($)	$648,576	$143,943
Casualty - Level 1	0.3322*	0.0154*
Casualty - Level 2	0.1048*	0.0019*
Casualty - Level 3	0.0176*	0.0001*
Casualty - Level 4	0.0352*	0.0002*

*Absolute number of persons in a given casualty level per year.

Calculations Completed Outside of HAZUS®MH

Annualized Losses	Original Building	Retrofitted Building
Casualty value	$151,343	$1,435

Annualized Benefit	
Reduced Building Capital Loss	$160,748
Reduced Direct Business Interruption Loss	$343,885
Reduced Environmental Loss	$38
Reduced Casualty Loss	$149,908
Benefits and Costs in Project Year	
Project Year	1997
Amortization Period	100 yr (lifeline)
Discount Rate (Non-casualty only)	2%
Reduced Building Capital Loss	$6,927,974
Reduced Direct Business Interruption Loss	$14,820,877
Reduced Environmental Loss	$1,638
Reduced Casualty Loss	$12,618,519
Cost	$26,449,484
Benefits and Costs in 2004	
CPI 2004/CPI 1997	1.188
Reduced Building Capital Loss	$8,230,433
Reduced Direct Business Interruption Loss	$17,607,201
Reduced Environmental Loss	$1,946
Reduced Casualty Loss	$14,990,800
Total Benefit	$40,830,380
Cost	$31,421,987
Benefit-Cost Ratio	1.30

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. (See Appendix H.)

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.

Box 2 provides an example of where relationships from HAZUS®MH were used to calculate the benefits of mitigation for a tornado-related project grant. Note that because HAZUS®MH currently does not address tornado hazards, almost all of the analysis was done outside of HAZUS®MH.

6.3.1.3 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 (see Section 4.3.1 for a description of this methodology). Casualties and displacement costs, and historic site and environmental benefits were calculated separately using the methodologies noted in Chapter 4. Because all mitigation measures applied to residential properties, no business interruption benefit was calculated.

The study investigators coded 71 grant 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 of 3,567 meters[67] to allow mapping in the FEMA Q3 digital flood map and the USGS National Hydrography Dataset (NHD) stream data (see Appendix G for a description of the databases). 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 grant, 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 projects have a

[67] 3,567 meters was chosen because it corresponds to the maximum geocoding error associated with rural areas.

Box 2 USE OF HAZUS®MH DAMAGE FUNCTIONS - Tornado

Background

HAZUS®MH damage functions were used to help calculate the benefits (i.e., reduction in number of casualties) associated with shelter installations, i.e., saferooms. In this case, the hazard being mitigated was tornado wind. Because HAZUS®MH is not currently set up to estimate tornado losses internally, the project investigators used the basic wind damage functions in HAZUS®MH (that are used for estimating the effects of hurricane wind) and applied these functions using an existing tornado risk assessment methodology (see Appendix H for details). The following example illustrates how these damage functions were used for a masonry school in the Midwest. To define the hazard potential for this region, an historic tornado incident catalog developed by NOAA was used.

Step 1: The tornado track data were aggregated to one-degree latitude by one-degree longitude grids. The count of tornado vectors by Fugita rating was extracted for the grid that contained the site location. The data were then normalized by the number of years surveyed in the NOAA dataset and adjusted using a linear multiplier for undercount.

Incidence of Tornados

	F-1	F-2	F-3	F-4	F-5
Total	39	13	16	2	0
Per Year	1.2675	.4225	.52	.065	.0

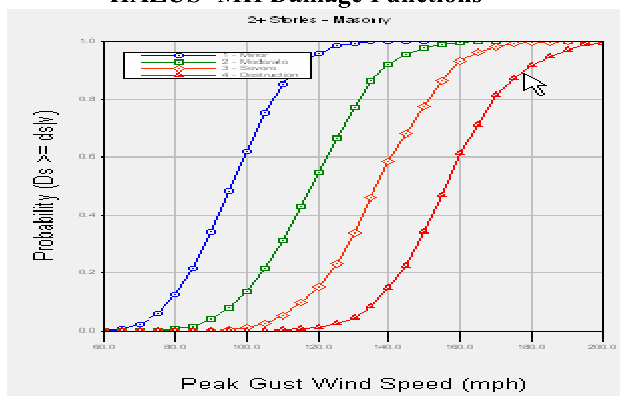
Step 2: A buffer was calculated for each tornado vector that represented the drop-off in wind speed with increasing distance from each tornado path. For each buffer, the length and width of degradation by Fujita scale was used to calculate a total degradation matrix. This step results in an (annualized) exposure area (sq. kms.) associated with each wind speed. Summing these exposure areas by wind speed and dividing by the total grid area yields an estimate of the annualized probability of the structure being exposed to a given wind speed.

Annualized Exposure Areas by Wind Speed

	100 mph	150 mph	200 mph	250 mph	300 mph
F-1	.061811	0	0	0	0
F-2	.103917	.054265	0	0	0
F-3	.552378	.289046	.175237	0	0
F-4	.209148	.13194	.060325	.037042	0
F-5	0	0	0	0	0
Total	.927253	.475251	.235563	.037042	0
Freq.	.000235	.000120	.000060	.000009	0

Step 3: HAZUS®MH damage functions were used to estimate the expected damage by damage state. The annual wind speed probabilities provided in Step 2 were multiplied by the probability of being in a given damage state. This resulted in the following damage state probabilities: minor: 2.87×10^{-4}, moderate: 1.12×10^{-4}, severe: 7.39×10^{-5}, and destroyed: 7.17×10^{-5}.

HAZUS®MH Damage Functions



Step 4: ATC (1985) injury and death rates, as applied by the FEMA Benefit-Cost Analysis toolkit, were used to estimate the number of injuries and deaths from tornado wind. These rates were multiplied by the (annualized) damage state probabilities above. For purposes of quantifying exposure, an average of 300 individuals were assumed to the shelter.

ATC (1985) Injury and Death Rates

	Minor injury	Major injury	Death
Minor	0.0001	0.00001	0
Moderate	0.0012	0.00016	0.00004
Severe	0.06857	0.00914	0.00229
Destruction	0.4	0.4	0.2

Step 5: Casualty rates were then converted into dollar amounts using $17,000 for minor injuries, $180,000 for major injuries and $3,000,000 for deaths. The value of avoided casualties for this sample is compared to the cost of the tornado mitigation projects to yield the benefit cost ratio.

Benefit-Cost Calculations

Annualized Avoided Casualty Benefits	$8,279
Discount Rate (Casualty)	0%
Amortization Rate	50 years
Total Casualty Benefit	$413,950
Project Cost	$327,000
Benefit Cost Ratio	1.27

mean benefit of $0.56 million and standard deviation of $0.85 million. The large project standard deviation 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 yield 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 report 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.

6.3.2 Sampled Grants for Process Mitigation Activities

This section presents the results for grants for process mitigation activities. The reader is reminded that 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 grants for process mitigation activities have the same benefit-cost ratio as the mitigation activities that they eventually inspire. The analysis was based on the “surrogate benefit” approach presented in Sections 2.3 and 4.3.5.

Only the following major types of process activities were evaluated:

1. Information/warning (risk communication),

2. Building codes and related regulations, and
3. Hazard mitigation plans.

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

6.3.2.1 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.

6.3.2.2 Grants for Wind Process Mitigation Activities

Twenty-one wind-related grants for process mitigation activities were evaluated. The average benefit-cost ratio is 1.2. Individual grant benefit-cost ratios ranged from 1.1 for risk communication activities to 1.4 for evaluation and training activities. 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.

6.3.2.3 Grants for Flood Process Mitigation Activities

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

6.3.2.4 Summary of Results for Process Mitigation Activity Grants

A conservative estimate of the benefit-cost ratio for most grants for mitigation planning is about 1.4 (for a further explanation of this and other benefit-cost ratios used in this analysis the reader is referred to Section 4.3.5 and Appendix K). 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 grants. For grants for activities involving building codes a conservative estimate is higher than for multihazard 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. (2004), 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 process for 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. However, when actual mitigation was quite costly, it was less likely that a grant for process activities was going to lead to positive net benefits.

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. As noted in this report, to do so 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 Section 5).

6.4 Extrapolation of Sample Results to Population

The results presented in previous sections were scaled to the population of grants using the arithmetic mean approach described in Section 4.5.3. These population totals are presented in Table 6-3 for grants for project and process mitigation activities. The results indicate that the present value discounted benefits for FEMA hazard mitigation grants 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 6-4 summarizes the calculation of stratum benefit-cost ratio. The benefit-cost ratios for project mitigation activities in descending size 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 6-3 Mitigation benefits and sample size by hazard (in 2004 dollars)

Hazard	Type	Population		Sample	
		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 discussed in sections 4.5.1 and 4.5.3. Stratum BCR is taken as 1/n*□(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 6-4 Scale-up of results to all FEMA grants
(all $ figures in 2004 constant dollars)

	Project Grants			Process Grants			Total
	Quake	Wind	Flood	Quake	Wind	Flood	
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

As shown in Figure 6-1, 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 and hurricane/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.

6.4.1 Breakdown of Results

The results are summarized by hazard type in Table 6-5, which shows that overall, mitigation for each hazard has a benefit-cost ratio greater than one, with flood being the most cost-beneficial (BCR = 5.0). Table 6-6 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.

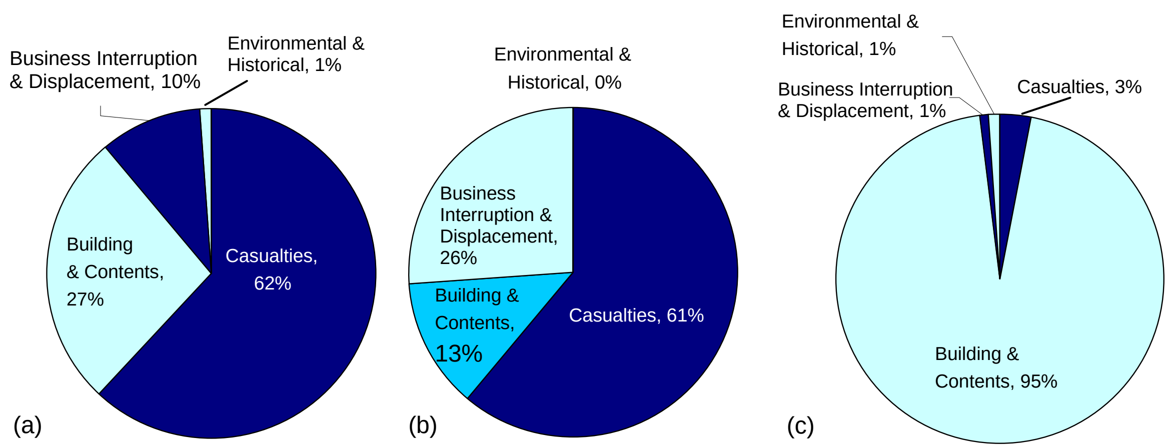


Figure 6-1 Contribution to benefit-cost ratio by factor for (a) earthquake, (b) wind, and (c) flood.

Table 6-5 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 6-6 Summary of benefits and costs by type of mitigation activity

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

In assessing the results, recall that grants for process mitigation 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. As shown in Table 6-6, benefits from grants for process mitigation activities represent 2.7 percent of FEMA grant total benefits to the nation. This is consistent with the result that the benefit-cost ratio for grants for project mitigation activities, which is estimated to be twice as high as for grants for process activities.

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 is higher than that for reducing casualty in the 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.[68] In a similar vein, a higher proportion of wind mitigation grants are 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.

Also, 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. Finally, 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 benefit-cost ratio as much as they did for overall wind benefit-cost ratio.

6.4.2 Deaths and Injuries

Table 6-7 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 exposed, 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 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 6-7, 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

[68] 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.

not able to be given to the financial benefit of these reductions, they are an important component of the benefit of mitigation.

6.4.3 Net Benefits to Society

As noted above, 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 (Table 6-7).

Table 6-7 Estimated reduction in casualties by grants for both project and process mitigation activities in sample and population of grants

	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

6.4.4 Impacts on the Federal Treasury

The methodology described in Section 4.5.4 was applied to estimating the potential future savings to the federal treasury of FEMA hazard mitigation grants. The two major categories of savings are:

1. Reductions in government spending on disaster recovery and future natural hazard mitigation.
2. Recouped federal taxes for reductions in individual and business casualty loss and increase in federal tax revenues from income subject to tax from individuals who avoided death or injury.

Individual components of these savings are listed in the Category column of Table 6-8, along with the sources of the base data. Adjustments made to the data are identified in the third and fourth columns and in the table notes. Examples of more straightforward adjustments include annual averaging and present value calculations. Other adjustments required that assumptions be made based on indications in the literature regarding insurance coverage and the ratio of government and nonprofit sector to total business losses. (Average tax rates are used rather than marginal rates because the latter would have required determination of the income status of all disaster victims.) In all, 10 different categories of savings are estimated.

Table 6-8 Annual potential savings to the Federal Treasury

Category	Base (2004 $ in millions)	Adjusted Base (2004 $ in millions)	Factor	Savings (2004 $ in millions)	Source of Base Data
Federal Government Expenditures Saved					
Public assistance	2,240.9	n.a.	.174[1]	389.9	FEMA (2005)
Individual assistance/human services	889.8	n.a.	.174	154.8	FEMA (2005)
Mission assignments /standby grants	126.6	n.a.	.174	22.0	FEMA (2005)
FEMA administrative costs	594.6	n.a.	.174	103.5	FEMA (2005)
Mitigation grants and contracts	386.7	n.a.	.174	67.3	FEMA (2005)
U.S. Small Business Administration default and administrative costs	463.4	n.a.	.174	80.6	SBA (2005)
U.S. Army Corps of Engineers emergency measures	104.8	n.a.	.174	18.2	USACE (2005)
Subtotal	n.a.	n.a.	n.a.	$836.3	
Federal Tax Revenues Recouped					
Individual income tax casualty loss deduction	1,061.3[2]	530.7[3]	.171[4]	90.7	This study
Individual income tax payments related to reduction in injury and death	208.9[5]	n.a.	.171	35.7	This study
Corporate income tax payments related to reduction in casualty loss business interruption	108.9[6]	23.0[7]	.252[8]	5.8	This study
Subtotal	n.a.	n.a.	n.a.	$132.2	
Grand Total	n.a.	n.a.	n.a.	$968.5	

n.a. — not applicable

[1]Ratio of average annual property damage and casualty (death and injury) reduction from grants for project and process mitigation activities in this study (present value for 50 years discounted at 2 percent, which amounts to $1.32 billion) divided by average annual property damage and casualty values from natural hazards in the U.S. ($7.6 billion in 2004 dollars), from University of South Carolina (2005).

[2]Based on avoided residential property damage from floods from average annual mitigation (present value discounted at 2 percent).

[3]Applied to uninsured household property damage associated with floods (FEMA-funded mitigation applicable to individual taxpayers pertains only to flood hazard). Assumes 50 percent of damage was uninsured. Proportion of individual property loss avoided to total property loss avoided from floods was based on ratio of private to total (private and public) number of properties mitigated. A further 10 percent reduction was assumed to cover people who do not itemize deductions and to cover the exclusion of individual casualty loss that can be deducted.

[4]10-year average individual tax rate for 1993-2002 (IRS, 2003; 2004a,b).

[5]Based on avoided death and injury from earthquake, wind, and flood from average annual mitigation (not discounted).

[6]Based on avoided private (not including public and nonprofit sector building) property damage and business interruption (including displacement costs) from earthquake and wind (FEMA flood mitigation had minimal application to business) from average annual mitigation (present value discounted at 2 percent). Assumes property damage to private sector was 1.0 percent of annual average total property damage in case of earthquake and wind. Assumes that private for-profit sector business interruption loss for earthquake and wind was 77 percent of total business interruption loss (based on national average of business activity in the for-profit sector).

[7]Assumes that 50 percent of business losses are insured.

[8]10-year average corporate tax rate for 1993-2002 (IRS 2003; U.S. Department of Commerce, 2003).

The estimate of the present value of total annual savings in terms of federal government expenditures in present value terms is $836.3 million. The largest category is FEMA Public Assistance ($389.9 million) and the smallest is U.S. Army Corps of Engineers emergency measures ($18.2 million).

The estimate of the present value of total annual savings in terms of recouped federal taxes is $132.2 million. The largest category here is income tax payments by those individuals who are spared casualty loss (in tax parlance, this refers to property rather than death or injury) ($90.7 million) and the smallest category is corporate income tax payments relating to reduced casualty loss and reduced business interruption to private entities ($5.8 million). The latter is rather small because the vast majority of federal mitigation grants go to public institutions, which do not have to pay federal business related taxes. The majority of the tax revenue benefits stem from utility customers.

The present value of total annual potential future savings to the federal treasury is $968.5 million. The average annual FEMA expenditure for hazard mitigation in the population of grants for which benefits were estimated in this study is $265.4 million (the federal share of the average annual cost of mitigation grants is 75 percent of $353.8 million). This means that on average every $1 of FEMA expenditures generates a present value of future savings to the federal treasury of $3.65. This result indicates that the FEMA hazard mitigation program more than pays for itself in terms of cost to the federal treasury. Also, this is to a great extent separate[69] from the benefits of avoided hazard losses to the American people.

The reader should bear two things in mind. First, the majority of the savings in Table 6-8 are not reductions in costs to society as a whole, but rather are transfers from one entity to another. Transfers do not represent the avoided destruction of real resources (e.g., buildings, human casualties, wetlands), but are only a shift of money from one entity to another, as in the payment of a tax or subsidy. Real resource savings are counted in the benefit-cost analysis. The entries in Table 6-8 that are not merely transfers are various administrative cost reductions and resources actually used in recovery and for future mitigation. Second, the savings are *potential*. Reduced hazard losses make private and public expenditures for recovery efforts unnecessary for those hazards that are mitigated. However, substantial unmitigated hazard losses may still attract federal and private assistance. These payments may not actually be reduced over the short term by the amount of the full potential savings identified in this report. The sum total of hazard recovery *needs*, however, is definitely reduced and is increasingly likely to lead to reductions in recovery spending in the long run.

The base numbers in this analysis reflect actual government expenditures and estimates of hazard losses presented in this report. Many of these bases required no adjustments for application of savings factors applied in this analysis, and the few that did were adjusted by standard tax code deductions. Some savings factors are simply average tax rates. The exception is the 17.4 percent annual hazard reduction rate, which was based on estimation of the present value of categories of commonly measured (property damage, death, and injury) avoided hazard losses in relation to like categories of total annual hazard losses (see also Section 4.5.4). The remaining assumption — that federal expenditures on disaster recovery is potentially reduced in full proportion to hazard losses — is one that can be argued both ways. The exact outcome is likely to lie somewhere between the extreme positions of no decrease, or a full decrease, in spending. This is the main reason why savings have been labeled as "potential." However, as mitigation cumulates, the reduced need for post-disaster expenditures will surely be evident.

[69] The overlap is limited to actual resource use for disaster recovery and natural hazard mitigation.

The estimates of savings are also in keeping with the objective of erring on the side of conservatism. Consequently, potential increased tax revenue associated with a possible reduced level of philanthropic giving, lower tax deductions, and potential reductions of HUD Block Grants were not included in this analysis.

6.5 Sensitivity Analysis

Sensitivity analyses were performed on the parameters listed in Table 4-11. Figures 6-2, 6-3, and 6-4 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.

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”[70] (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.

6.5.1 Grants for Earthquake Project Activities

Results for earthquake project mitigation benefits are illustrated in Figure 6-2. 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

[70] 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.

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.

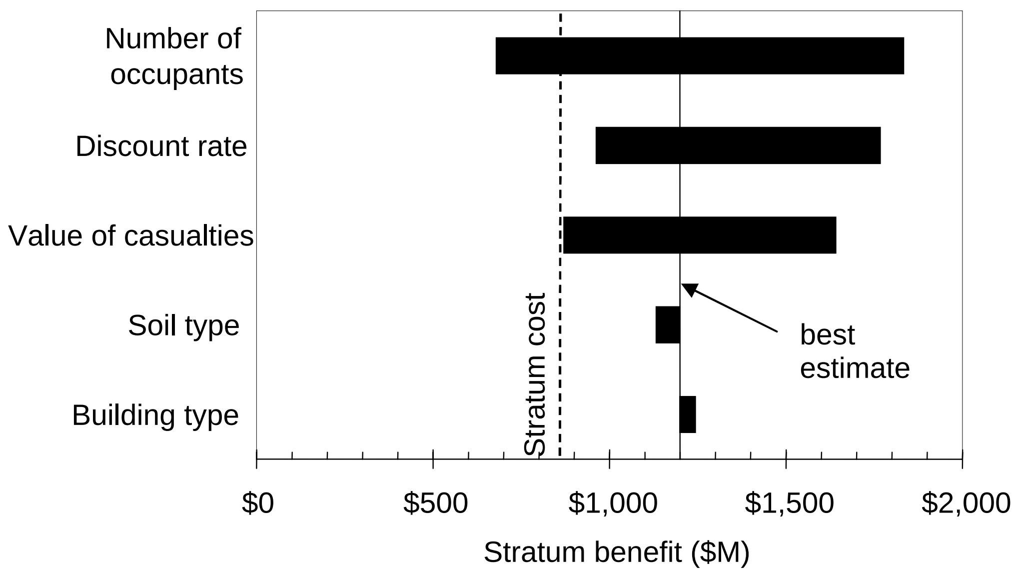


Figure 6-2 Sensitivity of benefit to uncertainties (grants for earthquake project mitigation activities).

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.

6.5.2 Grants for Wind Project Mitigation Activities

Figure 6-3 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.

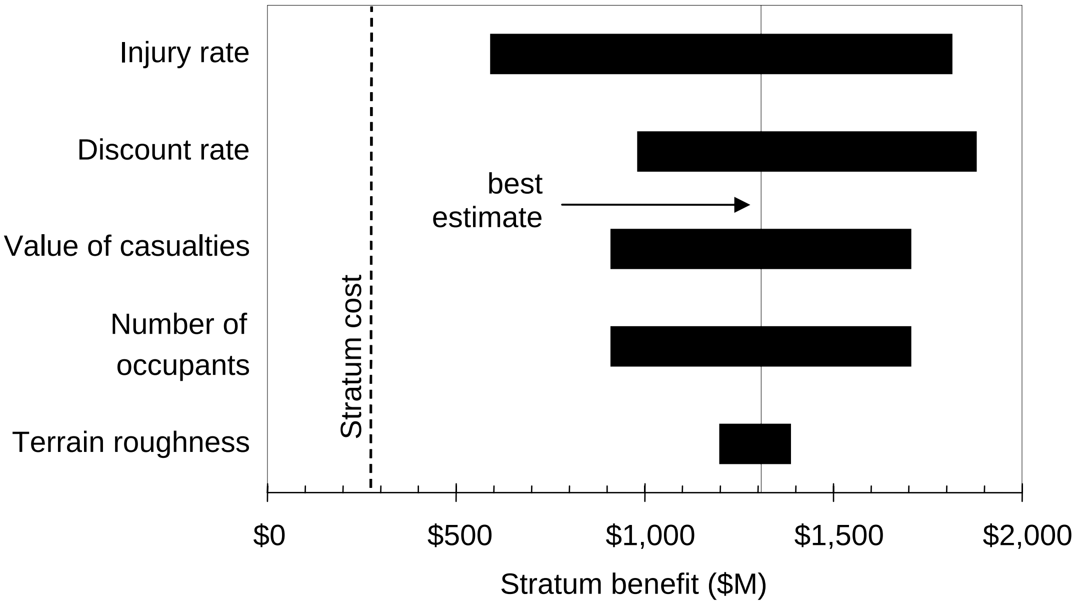


Figure 6-3 Sensitivity of benefit to uncertainties (grants for wind project mitigation activities).

6.5.3 Grants for Flood Project Mitigation Activities

Figure 6-4 shows the diagram for grants for flood project mitigation activities. Flood project benefits are most sensitive to discount rate, then 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, on average every $1 spent on flood project grants is estimated to save almost $5.

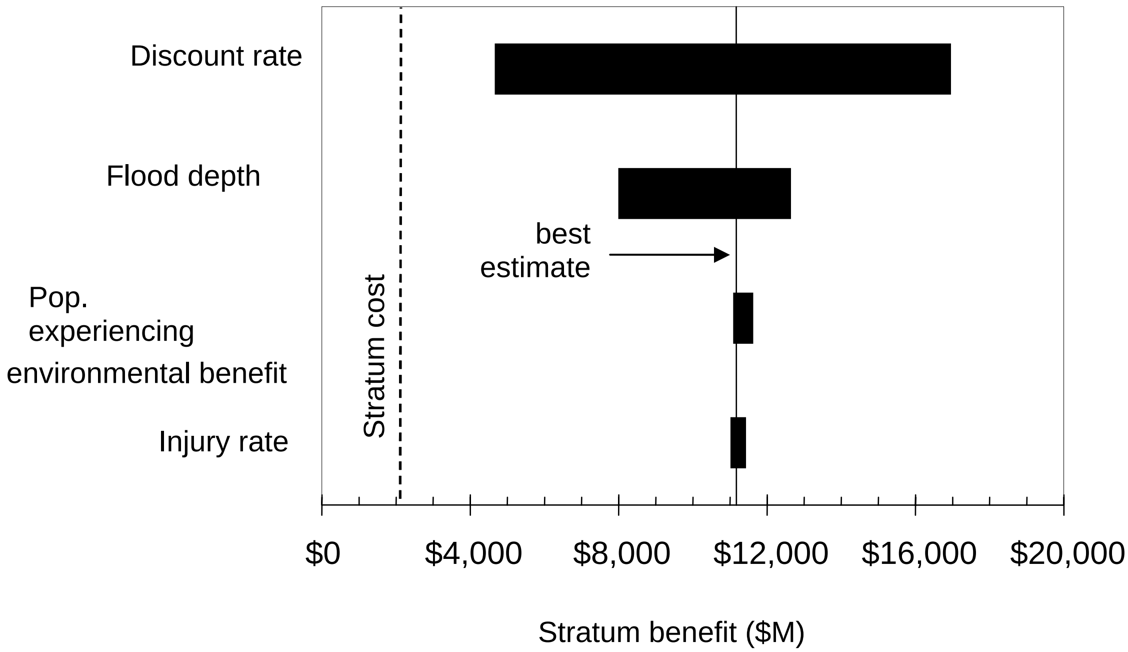


Figure 6-4 Sensitivity of benefit to uncertainties (grants for flood project mitigation activities).

6.6 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 projects affecting utilities), and the narrow variation in this parameter.

The unemployment rate, as a proxy for excess capacity, is one of several sources of resilience to disasters factored into this study. 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 (defined in Table 6-3) 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. The values provided by HAZUS®MH were used for these parameters (inventories, import and export of goods) and sensitivity analysis was 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.

The savings to the federal treasury are robust as well. Although no formal sensitivity tests were performed here, these estimates (i.e., savings to the federal treasury) are based on government expenditure data, loss estimation data estimated in this study (and for which sensitivity tests were performed), and straightforward parameters like federal tax rates and insurance coverage.

6.7 Combining Sampling Uncertainty and Modeling Uncertainty

As has been noted elsewhere, the total benefit of FEMA grants is uncertain. It is desired to quantify and combine all important sources of uncertainty. This information can then be used to calculate two interesting parameters: confidence bounds for the total benefit of FEMA grants for each hazard and the probability that the "true" benefits exceed the cost. By "confidence bounds" is meant 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 6-4, 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 6.5, via the standard deviation of benefit.

As detailed in 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.

6.8 Conclusions

This chapter summarizes the application of several practical methods to estimate the benefits of FEMA-funded hazard mitigation activities. These are not necessarily the ideal methods that one might consider for this purpose, were data and time less constrained (see the Scoping Study report (ATC, 2003a) for a discussion of various alternative methods). However, they represent the best practical methods available given limitations of data and time.

This study estimated that total benefits to the nation of FEMA mitigation grants between mid-1993 and mid-2003 yielded a present discounted value of $14 billion. (Grants outside of this date range and grants to mitigate risk from winter storm and some other hazards were not studied.) Compared to a cost of $3.5 billion, the overall benefit-cost ratio is 4.0. These results indicate that, on average, FEMA-funded project and process mitigation activities have benefit-cost ratios greater than 1.0 for all hazard types. In fact, for wind and flood projects, the benefit-cost ratios are 4.7 and 5.1, respectively. Grants for earthquake process mitigation activities have a high benefit-cost ratio of about 2.5 as well. Moreover, the sensitivity analyses performed indicate that these results are robust even to extreme variations in key parameters.

Potential annual savings to the federal treasury of these grants is estimated to be $969 million. Juxtaposed against grant costs, this means that on average every dollar of FEMA mitigation grant expenditures will potentially lead to an average of a $3.65 combination of reduction in future post-disaster relief and increased federal tax revenues. These results are robust as well.

The benefit-cost analysis of FEMA mitigation grants can be considered to have yielded lower-bound estimates for three reasons. First, the analysis used conservative assumptions regarding vulnerability of buildings, the scope of business interruption losses, and the extent of casualties. Second, "outliers" were excluded in calculating sample stratum benefit-cost ratios. Outliers with especially high benefit-cost ratios had the potential to significantly increase the sample mean benefit-cost ratio much more than outliers with low values had to decrease the sample mean. Third, several categories of the benefits of reduced losses were omitted because they could not be quantified. These include the avoidance of: several types of societal impacts related to psychological trauma; indirect property damage such as ancillary fires; environmental damage to complex ecosystems; air quality of burning debris; land-use and costs of reduced disposal of debris. It also excludes the outright benefits of the diffusion of hazard mitigation research and demonstration projects.