

1 Benefit-Cost Analysis of FEMA Hazard Mitigation Grants

2 Adam Rose¹; Keith Porter²; Nicole Dash³; Jawhar Bouabid⁴; Charles Huyck⁵; John Whitehead⁶;
3 Douglass Shaw⁷; Ronald Eguchi⁸; Craig Taylor⁹; Thomas McLane¹⁰; L. Thomas Tobin¹¹;
4 Philip T. Ganderton¹²; David Godschalk¹³; Anne S. Kiremidjian¹⁴; Kathleen Tierney¹⁵; and
5 Carol Taylor West¹⁶

6
7 **Abstract:** Mitigation decreases the losses from natural hazards by reducing our vulnerability or by reducing the frequency and magnitude
8 of causal factors. Reducing these losses brings many benefits, but every mitigation activity has a cost that must be considered in our world
9 of limited resources. In principle, benefit-cost analysis (BCA) attempts to assess a mitigation activity's expected net benefits (discounted
10 future benefits less discounted costs), but in practice this often proves difficult. This paper reports on a study that applied BCA method-
11 ologies to a statistical sample of the nearly 5,500 Federal Emergency Management Agency (FEMA) mitigation grants between 1993 and
12 2003 for earthquake, flood, and wind hazards. HAZUS MH was employed to assess the benefits, with and without FEMA mitigation in
13 regions across the country, for a variety of hazards with different probabilities and severities. The results indicate that the overall
14 benefit-cost ratio for FEMA mitigation grants is about 4:1, though the ratio varies from 1.5 for earthquake mitigation to 5.1 for flood
15 mitigation. Sensitivity analysis was conducted and shows these estimates to be quite robust.

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17 **CE Database subject headings:** Benefit cost ratios; Hazards; Disasters; Federal agencies; Remedial action.
18
19

20 Introduction

21 Background

22 Mitigation decreases the losses from natural hazards by reducing
23 our vulnerability or by reducing the frequency and magnitude of
24 causal factors. Mitigation would ideally be implemented as exten-
25 sively as possible, but, in a world of limited resources, its costs
26 must be considered. Benefit-cost analysis (BCA) is a widely used
27 tool to evaluate expenditures in this context (see, e.g., Zerbe and
28 Dively 1994; FEMA 2005). If a mitigation activity's total ex-
29 pected benefits (avoided losses) exceed its total costs, and at a

level comparable to both private and public investment rates of
return, then it represents an efficient use of society's resources. A
longstanding question has been: to what extent do hazard mitiga-
tion activities pass the BCA test?

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

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

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

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

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

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

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

⁷Professor, Agricultural Economics Dept., Texas A&M Univ., Mail-stop 2124, College Station, TX 77843.

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

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

¹⁰Director of Business Development, Applied Technology Council, 211 Wilson Boulevard, Suite 700, Arlington, VA 22201. E-mail:

tmclane@atcouncil.org

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

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

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

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

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

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

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

44 Overview

45 The results of the benefit-cost analysis of FEMA hazard mitiga-
46 tion grants are presented and explained below. These results are
47 based on the data and methods summarized in MMC (2005,
48 Chaps. 3 and 4). Results are presented for two major categories of
49 grants—project activities and process activities; and for three
50 hazards—earthquake, flood, and wind (hurricanes, tornados, and
51 other windstorms), for a total of six strata. The results for a third
52 category of grants, Project Impact grants, are presented in MMC
53 (2005, Chap. 5). The grant programs analyzed in this paper rep-
54 resent 72% of all FEMA hazard mitigation grants and 80% of all
55 associated FEMA expenditures during the study period. Specific
56 methods and data used in the estimation of each stratum are also
57 briefly summarized.

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

67 Overall, the benefit-cost analysis of FEMA hazard mitigation
68 grants found that the benefit-cost ratio (BCR) of each stratum was
69 greater than 1.0. Moreover, this result is robust to formal sensi-
70 tivity tests (tornado-diagram analyses, discussed later) and infor-
71 mal evaluations of methodological limitations and assumptions
72 (discussed throughout the present paper). The total national ben-
73 efits of FEMA hazard mitigation grants between mid-1993 and
74 mid-2003, in terms of avoided future losses during the useful life
75 of these mitigation efforts (which varies by grant) are estimated to
76 be \$14.0 billion in year 2004 constant dollars, compared with
77 \$3.5 billion in costs. This yielded an overall BCR of 4.0. Thus,
78 every dollar spent on a FEMA hazard mitigation grant produced,
79 on average, four dollars of benefits—a significant return on public
80 dollar expenditures, comparable to a 14% rate of return on a
81 50-year annuity.

82 Methodology

83 The benefits of hazard mitigation are the avoided losses, i.e.,
84 those losses that would have occurred (in a probabilistic sense) if
85 the mitigation activity had not been implemented. It is important
86 at the outset to note two key differences between mitigation costs
87 and benefits. Mitigation costs are incurred primarily during a
88 short period, such as during construction, and are relatively cer-
89 tain. The only exception pertains to operating costs and mainte-
90 nance costs, but these are usually relatively minor in comparison
91 to construction costs. Mitigation benefits, however, accrue over
92 the useful life of the project or process activity and are highly
93 uncertain because they are usually realized only if natural hazard
94 events occur. At best, the expected value of benefits of mitigation
95 measures currently in place can only be approximated by multi-
96 plying the potential total benefits of an event of various sizes by
97 the probability of each event, and summing over all such events.
98 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). 99 100

The various categories of hazard mitigation benefits addressed
in this paper are as follows: 101 102

1. Reduced direct property damage (e.g., buildings, contents,
bridges, pipelines); 103 104
2. Reduced direct business interruption loss (e.g., factory shut-
down from direct damage or lifeline interruption); 105 106
3. Reduced indirect business interruption loss (e.g., ordinary
economic “ripple” effects); 107 108
4. Reduced (nonmarket) environmental damage (e.g., wetlands,
parks, wildlife); 109 110
5. Reduced other nonmarket damage (e.g., historic sites); 111
6. Reduced societal losses (deaths, injuries, and homelessness);
and 112 113
7. Reduced emergency response (e.g., ambulance service, fire
protection). 114 115

Compared to benefit-cost analysis, loss estimation modeling is
relatively new, especially with respect to natural hazard assess-
ment. 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 emer-
gence 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). 116 117 118 119 120 121 122 123 124

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 non-
technical hazard specialists. The resulting tool, a software pro-
gram called Hazards US-Multi-hazard (HAZUS MH), currently
addresses earthquake, flood, and hurricane winds. HAZUS MH
was extensively used in this study. A summary of HAZUS MH is
presented in Appendix I, and more details of its application are
presented during the course of the discussion below. 125 126 127 128 129 130 131 132 133 134 135

Not all benefits of mitigation evaluated in this study can be
analyzed using traditional evaluation methods. Alternative ap-
proaches for assessing some categories of mitigation benefits
were needed. For environmental and historic benefits, a feasible
approach for measuring the benefits of hazard mitigation is the
benefit transfer approach (see, e.g., Brookshire and Neil 1992;
Bergstrom and DeCivita 1999). Valuation of environmental dam-
ages, cultural and historical damages, and lives is conducted by
converting these “nonmarket” damages into dollars with the will-
ingness to pay paradigm. The benefit of a policy is thus the
amount of money, over and above expenditures or impacts, that
members of society are willing to pay to obtain an increment in
wellbeing or avoid a decrement in wellbeing. Willingness to pay
is the theoretically correct measure of the economic benefits of a
policy or project. Nonmarket valuation methodologies convert the
intrinsic value of a nonmarket good into dollar values that can be
added up and directly compared to policy costs. When the cost of
primary data collection is prohibitive, as in this study, the benefit
transfer approach is invoked, adapting previous estimates of will-
ingness to pay. 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155

Several assumptions underlie the analysis. Here we note the
major ones and refer the reader to Appendix II for others. The
base case real discount rate used is 2%, which is based on market
interest rates. It is also the same rate that is recommended by the
Congressional Budget Office, which is based on an estimate of
the long-term cost of borrowing for the federal government (see 156 157 158 159 160 161

162 “Treasury quotes” 2003) and is generally considered a conserva-
 163 tive estimate of the long-term real market risk-free interest rate.
 164 (Results were sensitivity tested to discount rates between 0 and
 165 7%, along with sensitivity tests of a variety of other model pa-
 166 rameters.) The planning period was taken as 100 years for miti-
 167 gation of important structures and infrastructure and 50 years for
 168 all other mitigation measures, regardless of property age. Avoided
 169 statistical deaths and injuries were valued using FHWA (1994)
 170 figures, brought to 2002 constant dollars (using the consumer
 171 price index), but not time discounted primarily because this
 172 would imply a death or injury in the future is worth less than
 173 today.

174 Translating injuries and loss of life into quantifiable dollar
 175 figures is difficult. Estimates of the value of life vary greatly—
 176 from \$1 to \$10 million depending on the agency making the
 177 assessment or the use of the figure (see Porter 2002 for discus-
 178 sion). One of the more applicable figures is from a study for the
 179 Federal Aviation Administration (1998), in which the authors se-
 180 lect a value of \$3 million per statistical death avoided, in order to
 181 value the benefit of investment and regulatory decisions.

182 Quantifying the costs of injuries is equally problematic. Little
 183 research has focused specifically on the cost of injuries from di-
 184 sasters. However, the Federal Highway Administration (1994)
 185 published a technical report that provided figures of estimated
 186 costs of damages in car accidents. These comprehensive costs
 187 include, but are not limited to: lost earnings, lost household pro-
 188 duction, medical costs, emergency services, vocational rehabilita-
 189 tion, and pain and lost quality of life (FHWA 1994). This severity
 190 scale, however, does not map directly into the HAZUS 4-level
 191 scale, and as such has been modified for this project. Using a
 192 geometric mean approach to combine categories, minor and mod-
 193 erate severity costs were merged for the HAZUS 1 level; the
 194 serious severity level was used for HAZUS level 2; and severe
 195 and critical severities were merged to form the HAZUS level 3
 196 estimate. As discussed earlier, the FAA value of human life was
 197 used to represent the HAZUS level 4 category.

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

213 Grant Selection

214 This study addresses all FEMA-funded mitigation grants that sat-
 215 isfy the following criteria: (1) the grant was listed in the National
 216 Emergency Management Information System (NEMIS) database
 217 provided by FEMA in July 2003; (2) the grant was associated
 218 with disaster number 993 (Midwest floods of June 1993) or
 219 higher; and (3) the grant was intended to reduce future losses
 220 associated with earthquake, flood, or wind risk from hurricanes or
 221 tornadoes, as determined using FEMA’s project-type code in

NEMIS. Where the project-type code did not reveal the hazard to
 be mitigated, the hazard was assumed to be the same as that of the
 declared disaster, and this assumption was crosschecked by a re-
 view of the grant application.

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

Project Impact was a program funded between fiscal years
 1997 and 2001. Unlike the HGMP, which provides funding after
 disasters, PI supported the development of predisaster mitigation
 programs. In total, 250 communities across all states and some
 United States territories received \$77 million in grants. The one-
 time Project Impact grants were considered seed money for build-
 ing 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 natu-
 ral disasters.

The Flood Mitigation Assistance Program (FMAP) was cre-
 ated 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 pro-
 vides funding to assist states and communities in implementing
 measures to reduce or eliminate the long-term risk of flood dam-
 age to buildings, manufactured homes, and other structures insur-
 able under the National Flood Insurance Program. Annual funding
 of \$20 million from the National Flood Insurance Fund is allo-
 cated 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. Approxi-
 mately \$200 million in grants were not addressed for any of sev-
 eral reasons but primarily because they did not address one of the
 three hazards (earthquake, flood, and wind) examined in this
 study. Also, this paper reports only on the benefits of HMGP
 grants. The reader is referred to MMC (2005) for a discussion of
 PI grants.

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

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

Hazard	Type	Population		Sample	
		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

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

294 Grant data were acquired in electronic format for 5,479 ap-
 295 proved or completed grants to mitigate flood, earthquake, or wind
 296 risk. The data were stratified by hazard type (flood, earthquake, or
 297 wind) and mitigation type (project or process activity). A selec-
 298 tion of 357 mitigation grants was made for detailed examination
 299 based on a stratification scheme and minimum sample size crite-
 300 rion developed early in the project. The study investigators col-
 301 lected additional data on as many of these grants as possible (see
 302 MMC 2005, Chap. 3).

303 A rigorous random sampling technique was applied to select
 304 these 357 grants (see MMC 2005, Chap. 4 for details). In particu-
 305 lar, grants in each stratum were sorted in order of increasing cost.
 306 The stratum was then divided into a number of substrata of ap-
 307 proximately equal total cost, and sample grants were selected at
 308 random from within each substratum. The sample grants thus rep-
 309 resent the distribution of mitigation costs and to ensure the inclu-
 310 sion of low, medium, and high-cost mitigation efforts in each
 311 stratum. FEMA was able to provide paper copies of 312 grant
 312 applications. The paper grant-application files tended to contain
 313 more descriptive information about grants than did the NEMIS
 314 database. (All paper grant applications and the NEMIS database
 315 provided by FEMA were forwarded by the writers to the Wash-
 316 ington, D.C. office of NIBS, where they can be reviewed by
 317 interested parties.) Of these, 136 contained sufficient data to per-
 318 form a benefit-cost analysis. Data were extracted from these paper
 319 files and transcribed to electronic coding forms in a detailed and
 320 structured fashion. The form for project mitigation activities con-
 321 tained 200 data fields for each property or location mentioned in
 322 the grant application. Eventually, 54,000 data items were ex-
 323 tracted for the stratified sample, consisting of 1,546 properties in
 324 project mitigation activities and 387 distinct efforts in process-
 325 type activities, representing nearly \$1 out of every \$6 spent on
 326 hazard mitigation in the population of grants examined here.

327 Table 1 summarizes the distribution of these grants by mitiga-
 328 tion type and hazard for the entire population of grants that satisfy
 329 the criteria listed above and for the sample that was selected to
 330 represent the population. The table distinguishes grants that in-
 331 volve the actual mitigation of risk (*project* mitigation activities)
 332 from activities involving support functions (*process* mitigation
 333 activities). Project activities include physical measures to avoid or

reduce damage resulting from disasters. Typically they involve
 acquiring and demolishing, elevating, or relocating buildings,
 lifelines, or other structures threatened by floods; strengthening
 buildings and lifelines or their components to resist earthquake or
 wind forces; or improving drainage and land conditions. Process
 activities lead to policies, practices, and other activities that re-
 duce risk. These efforts typically focus on assessing hazards, vul-
 nerability, and risk; conducting planning to identify mitigation
 efforts, policies, and practices, and to set priorities; educating
 decision makers, and building constituencies; and facilitating the
 selection, design, funding, and construction of projects. See
 MMC (2005, Chap. 2) for a more extensive discussion of the
 distinction between project and process grants.

Sample Results

Sampled Grants for Project Mitigation Activities

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

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

Grants for Earthquake Project Mitigation Activities

The earthquake stratum of grants for project mitigation activities
 includes grants for both structural activities (e.g., base isolation of
 public buildings) and nonstructural activities (e.g., retrofit of pen-
 dant 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 miti-
 gation of seismically vulnerable light fixtures in 78 buildings.
 Higher-cost grants included seismic upgrades and seismic safety
 corrections of hospitals, university buildings, and other public
 buildings.

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

New methods were developed for estimating some types of
 avoided losses, including business interruption impacts associated
 with utility outages, damage to pendant lighting and ceilings,
 environmental/historical benefits, and some societal benefits. The
 simple average benefit-cost ratio for the 25 grants in this stratum
 is 1.4, with a standard deviation of 1.3. The total benefit for this
 stratum is \$1.2 billion. Individual grant benefit-cost ratios range
 from near zero for a nonstructural retrofit to an electricity substa-
 tion (intended to reduce physical injury to workers) to 3.9 for a

392 nonstructural retrofit of a hospital. Note that the presence of indi- 455
 393 vidual grants with estimated BCR <1 does not indict FEMA 456
 394 grant making. Not all details considered in the original grant ap- 457
 395 plication necessarily appear in the paper copy of the grant appli- 458
 396 cation transmitted to the project team. 459

397 HAZUS MH was used to estimate property damage avoidance 460
 398 (benefits) due to the structural upgrades. The total property loss 461
 399 reduction for this stratum is \$319 million. Property loss reduction 462
 400 alone, however, was not sufficient for the average benefit-cost 463
 401 ratio from mitigation measures in this stratum to exceed 1.0. Of 464
 402 the 25 hazard mitigation grants in the earthquake project stratum, 465
 403 three avoided business interruption. The cases where business in- 466
 404 terruption was applicable included impacts on utilities and hospi- 467
 405 tals; no conventional business activities other than these were in 468
 406 the sample. (This estimation here and for other hazards excludes 469
 407 business interruption caused by damage to public buildings such 470
 408 as police and fire departments, civic arenas, and schools. These 471
 409 public sector activities, although not priced as a business product 472
 410 or service, do yield commensurate value even if usually not trans- 473
 411 acted through the market. However, they have been omitted from 474
 412 business interruption calculations because, in the aftermath of a 475
 413 natural disaster, most of their functions are provided by other 476
 414 locations or “recaptured” at a later date. Moreover, payments for 477
 415 major inputs continue even when the original facility is closed 478
 416 e.g., wages to unionized employees.) In addition, an inherent as- 479
 417 sumption of the HAZUS MH methodology is that only *structural*
 418 mitigation results in business interruption benefits. The vast ma-
 419 jority of *nonstructural* mitigation measures in this stratum are for
 420 pendant lighting in schools, and are assumed only to affect casu-
 421 alty rates.

422 For the three applicable cases in the earthquake project grant 480
 423 sample stratum, business interruption benefits average \$52.9 mil- 481
 424 lion, and range from a low of \$1.3 million for a pump station to a 482
 425 high of \$139.5 million for a hospital. Here and elsewhere in the 483
 426 study, we factored in some aspects of “resilience” to business 484
 427 interruption, or the ability to mute potential losses through inher- 485
 428 ent features of business operation (e.g., input substitution or using 486
 429 excess capacity) as well as adaptive behavior (identifying new 487
 430 sources of supply or making up lost production at a later date) 488
 431 (see, e.g., Rose 2004a). Business interruption benefits contribute 489
 432 about 10% to the overall average benefit-cost ratio for this 490
 433 stratum. 491

434 The largest component of benefits in the earthquake project 492
 435 stratum was the reduction of casualties, which accounted for 62% 493
 436 of the total benefits. Analysis shows that a reduction of about 542 494
 437 injuries and 26 deaths in this stratum sample is expected. Extrapo- 495
 438 lating to the entire stratum population, it is estimated that these 496
 439 grants result in avoiding 1,399 injuries and 67 deaths. The mean 497
 440 total benefit per grant is about \$6.3 million, with a standard de- 498
 441 viation of \$6.4 million. The projects with zero calculated casualty 499
 442 benefits included electrical substation upgrades, a school arcade 500
 443 replacement, and nonstructural mitigation activities to emergency 501
 444 power and communication facilities (rather than patient services) 502
 445 in a hospital. 503

446 Three earthquake grants in the sample provided environmental 504
 447 or historical benefits, including improving water quality, protect- 505
 448 ing historic buildings, and positive health benefits. The highest 506
 449 environmental benefit was for an earthquake retrofitting of a po- 507
 450 lice headquarters building (\$293,000), while the lowest pertains 508
 451 to health benefits of a hospital retrofit. The average benefit of 509
 452 these three grants is nearly \$143,000, and they accounted for less 510
 453 than 1% of the total benefits in the earthquake project grant stra- 511
 454 tum. No significant outliers exist in the earthquake project stra-

tum, with the exception of two nonstructural mitigation grants. 455
 These two grants did not provide much property protection, 456
 almost no casualty reduction, and no protection at all against busi- 457
 ness interruption. Those projects with low benefit-cost ratios in- 458
 clude some cases of nonstructural mitigation intended primarily 459
 for life safety. Other cases of this same type of mitigation yield 460
 some of the higher benefit-cost ratios, along with structural retro- 461
 fit of large buildings. The seeming incongruity of the benefits of 462
 nonstructural retrofits is explained primarily by differences in the 463
 number of individuals at risk of death and injury. 464

For this stratum, as well as for the others below, the overall 465
 approach was conservative (i.e., we made our decisions about 466
 assumptions, data, inclusion, in nearly all cases so as to err on the 467
 side of obtaining low benefit estimates). In this stratum, estimates 468
 of the diffusion of university research and of demonstration 469
 projects, as well as several types of societal impacts related to 470
 psychological trauma, were omitted because there was no ad- 471
 equate means of quantifying these measures. Also omitted in this 472
 and other strata were: indirect property damage (e.g., prevention 473
 of ancillary fires), avoided negative societal impacts relating to 474
 psychological trauma (e.g., crime, divorce), air quality benefits 475
 (improvements in visibility and health due to reduced burning 476
 debris), benefits from reduced disposal of debris (land quality), 477
 and aesthetic benefits including visibility and odors of reduced 478
 debris. 479

Grants for Wind Project Mitigation Activities 480

Although several mitigation measures are included in the sample 481
 grants for the wind project grant stratum, the majority deal with 482
 hurricane storm shutters and saferooms. HAZUS MH readily 483
 handles property benefit calculations for hurricane storm shutters. 484
 However, supplemental methodologies were developed by the 485
 study investigators to estimate property damage impacts of torna- 486
 does and casualty impacts for both hurricanes and tornadoes. 487
 Benefit transfer methods were used to estimate environmental/ 488
 historic benefits. 489

The simple average benefit-cost ratio for the 42 grants in the 490
 wind project stratum was 4.7, and the standard deviation was 7.0. 491
 The total benefit for this stratum is \$1.3 billion. Individual grant 492
 benefit-cost ratios range from less than 0.05 for retrofit of a police 493
 department building to greater than 50, for a variety of utility 494
 protection measures. 495

Benefit-cost ratios outside these bounds were ignored for the 496
 purpose of calculating the stratum-average benefit-cost ratios, 497
 which results in a conservative estimate. That is, estimated ben- 498
 efits would have been greater had these samples been included. 499
 The projects with a benefit-cost ratio less than 0.05 or greater than 500
 50 are referred to here as outliers; all projects with benefit-cost 501
 ratio between 0.05 and 50 are referred to as the censored set. The 502
 bounds of 0.05 and 50 were initially selected somewhat arbi- 503
 trarily. However, when one calculates the 1st and 99th percentiles 504
 of the lognormal distribution with the same moments as the cen- 505
 sored set (± 2.3 SD), all members of the censored set have benefit- 506
 cost ratios within these 1st and 99th percentiles, so the bounds are 507
 in a way “stable.” Note that the benefit-cost ratios of the censored 508
 set are approximately lognormally distributed, passing a 509
 Kolmogorov–Smirnov goodness-of-fit test at the 5% significance 510
 level. 511

Several of the grants that had large benefit-cost ratios (>10), 512
 including all four outliers that exceeded 50, were cases of electric 513
 utility mitigation, such as relocating utility power lines below 514
 ground. In these cases, property damage savings were relatively 515
 small, but the business interruption savings were large. A downed 516

517 power line, or a substation that has been disrupted because of a
 518 hurricane, can cause the economy of a city to come to a halt for
 519 days (Rose et al. 1997). Even the prevention of an outage of a few
 520 hours can pay for itself several times over in some instances.
 521 Property loss benefits can be significant, with reductions mea-
 522 suring up to four times the cost of the retrofit. The sample average
 523 benefit-cost ratio associated with property loss reduction is 0.59.
 524 The estimated total reduction in property loss for all wind project
 525 grants (not just those in the sample) is \$166 million.
 526 Casualty benefits apply to 25 grants in the wind stratum. All of
 527 these projects are either hurricane shelters or tornado saferooms.
 528 The hurricane grants involved mitigation of multiple properties,
 529 usually schools; however, not all of the schools are on the shelter
 530 inventory. The methodology calculated benefits for only those
 531 schools that also serve as hurricane shelters. Collectively, the
 532 schools that met this condition were able to shelter, at capacity,
 533 about 33,189 evacuees. The tornado grants involved the building
 534 of saferooms in public and private spaces, the majority of which
 535 were community shelters (sheltering 750–1,000) with one notable
 536 exception that sponsored the construction of saferooms in hun-
 537 dreds of private residences.
 538 Considering both types of wind project grants—hurricane and
 539 tornado—together, mitigation activities reduced casualty losses in
 540 the sample by about \$108 million, or an estimated \$794 million
 541 for all wind project grants. The per-project mean casualty benefit
 542 is \$4.3 million.
 543 Some intangible benefits of shelters could not be quantified,
 544 and were therefore excluded from the benefit-cost analysis.
 545 Regardless of the financial benefit of sheltering, shelters are ben-
 546 efiticial by reducing uncertainty and stress in those at risk. In
 547 addition, available hurricane shelter space keeps people off the
 548 highways during dangerous periods. More important, shelters
 549 offer the only safe haven for those without the financial means to
 550 take other protective measures.
 551 Historical benefits were applicable to only one wind hazard
 552 grant: door and window protection for an historic town hall (a
 553 total estimated benefit of \$115,000). For the wind project grant
 554 stratum overall, however, historic benefits contributed little to the
 555 average benefit-cost ratio.
 556 Estimates of casualties avoided because of grants for wind
 557 mitigation project activities are high compared to the number of
 558 lives lost annually from high wind in the United States. In this
 559 study, the estimated casualties avoided are all tornado related.
 560 Because the body of peer-reviewed scientific literature relating to
 561 probabilistic estimates of loss reduction from tornado mitigation
 562 is scant relative to that of other natural hazards covered in the
 563 study, the project investigators developed loss models without
 564 benefit of years of input from the scientific community in devel-
 565 oping, testing and validating modeling techniques.
 566 Because of these issues, ATC contracted with Professor James
 567 McDonald of Texas Tech University, a noted wind engineering
 568 expert, to review and comment on the entire loss estimation meth-
 569 odology for tornado. Because of this review, changes were made
 570 to the methods used to quantify tornado impact areas. The Project
 571 Management Committee and the Internal Project Review Panel
 572 agree that the model used is logical. Avoided casualties have a
 573 limited effect on the aggregate results of the current study. The
 574 sensitivity analysis found that the benefit-cost ratio for the stratum
 575 of grants for wind project mitigation remained above 1.0 when
 576 casualty rates were reduced an order of magnitude lower than the
 577 estimated rates. If only 10% of the estimated benefits attributed to
 578 avoided casualties are counted, the benefit-cost ratio for grants for
 579 wind-project mitigation activities would decline from 4.7 to 2.1.

Moreover, given the relatively small number and size of grants 580
 for wind mitigation, the benefit-cost ratio of all mitigation pro- 581
 grams would be reduced from 4.0 to 3.8. 582

Grants for Flood Project Mitigation Activities 583

HAZUS MH damage functions formed the basis for estimating 584
 property damage due to flooding. The hazard calculations, how- 585
 ever, were performed outside of the HAZUS MH flood module 586
 because this component was not available at the time of this 587
 study. Instead, an alternative methodology was developed that 588
 used a probabilistic approach to locate properties in the flood 589
 plane and to estimate the expected distribution of flood heights. 590
 Casualties and displacement costs, and historic site and environ- 591
 mental benefits were calculated separately using the methodologi- 592
 es summarized in MMC (2005, Chap. 4). Because all mitigation 593
 measures applied to residential properties, no business interrup- 594
 tion benefit was calculated. 595

The study investigators coded 71 project files (consisting of 596
 990 properties) into the project database. Approximately two- 597
 thirds, 625 properties, were geocoded through a combination of 598
 address matching tasks: (1) matching to previously located prop- 599
 erties in the NEMIS database; (2) geocoding using TIGER street 600
 data; and (3) matching addresses with geographic coordinates 601
 using online services such as MapQuest. 602

Out of the 625 geocoded buildings, 486 were within an accept- 603
 able distance to allow mapping in the FEMA Q3 digital flood map 604
 and the USGS National Hydrography Dataset (NHD) stream data. 605
 Several projects were subsequently eliminated from the analysis 606
 because of insufficient data. A final selection of 483 properties 607
 corresponded to 22 grants. For each flood project, only properties 608
 that matched all the above criteria were analyzed for direct prop- 609
 erty damage. 610

The number of geocoded properties within the acceptable dis- 611
 tance in a single grant ranged from 1 to 133, with a mean of 42 612
 and a standard deviation of 33. The property benefits realized for 613
 grants range from \$0.19 to \$1.1 million. The average benefit per 614
 property ranged from \$0.13 to \$0.74 million, with an average 615
 benefit of \$0.28 million, and a standard deviation of \$0.14 mil- 616
 lion. The only significant outlier was the acquisition of a school, 617
 with a total benefit of \$18.7 million. 618

Grants for flood acquisition projects also reduce the societal 619
 impacts of flooding by reducing injuries to the residents of the 620
 properties. For the flood project grant stratum, 22 grants had 621
 enough data to estimate casualty reduction benefits. The grants 622
 varied in size, with some mitigating many properties and others 623
 only a few. Overall, buying these properties reduced approxi- 624
 mately 68 injuries for a total benefit of \$12.3 million. On average, 625
 the 22 grants have a mean benefit of \$0.56 million and standard 626
 deviation of \$0.85 million. The large standard deviation for flood 627
 project grants results from the large grant size range. 628

The majority of the grants in the flood project grant stratum 629
 were for residential structures that had experienced repeated 630
 flooding. Costs associated with residential flooding included dis- 631
 placement costs for the families to relocate while their homes 632
 underwent repair. By buying out repeatedly flooded properties, 633
 mitigation activities reduced displacement expenditures. Twenty 634
 two sampled grants included sufficient information to estimate 635
 displacement costs. The total sampled stratum benefit is \$2.3 636
 million. 637

Sixteen of the flood mitigation grants yielded environmental 638
 benefits, and none yielded historical benefits. Fourteen of the en- 639
 vironmental benefits pertained to establishing wetlands following 640
 the removal of structures, rather than direct environmental ben- 641

642 efits of reduced flooding per se. The environmental benefits of
 643 these grants were estimated by applying wetland values from the
 644 literature to each acre created. Conservative assumptions were
 645 made about the wetland acreage created for each property pur-
 646 chased, the percentage of these acres that actually function as
 647 wetlands, and the number of years that the acreage would func-
 648 tion as such. Strictly speaking, these are side effects of mitigation,
 649 rather than intended consequences. This analysis could have listed
 650 them as offsets to mitigation costs, but it is less confusing to list
 651 them under benefits.

652 The grant with the highest environmental benefit was for the
 653 purchase and removal of 262 flooded properties (approximately
 654 \$0.32 million), while the lowest benefit was for the purchase and
 655 removal of one flooded property (approximately \$6,000). The av-
 656 erage environmental benefit associated with these 16 grants is
 657 nearly \$96,000.

658 The total of all benefits realized for each grant ranged from
 659 \$0.19 to \$116.5 million, with a standard deviation of \$27.3 mil-
 660 lion. The high standard deviation is directly attributable to the
 661 differences in the number of acquisitions.

662 All individual flood grants had benefit-cost ratios greater than
 663 1.0, with an average benefit-cost ratio of 5.1, a minimum of 3.0, a
 664 maximum of 7.6, and a standard deviation of 1.1.

665 *Sampled Grants for Process Mitigation Activities*

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

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

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

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

688 *Grants for Earthquake Process Mitigation Activities*

689 Twenty earthquake grants for process mitigation activities were
 690 evaluated. The average benefit-cost ratio of the sample is 2.5.
 691 Benefit-cost ratios for individual grants ranged from 1.1 for an
 692 engineering task force, to 4.0 for several grants for hazard miti-
 693 gation plans and building codes. The surrogate benefit methodol-
 694 ogy analyzes each grant in its entirety and does not separate out
 695 the different types of benefits as was done for grants for project
 696 mitigation activities. The methodology does not lend itself to the
 697 calculation of the standard deviation of benefit-cost ratio, so that
 698 figure was omitted here. The majority of grants for earthquake
 699 process mitigation activities are for mitigation plans and improve-
 700 ment of building codes and regulations. The only grant for infor-
 701 mation activities was for vulnerability evaluations.

Grants for Wind Process Mitigation Activities 702

Twenty-one wind-related grants for process mitigation activities 703
 were evaluated. The average benefit-cost ratio is 1.7. Individual 704
 grant benefit-cost ratios ranged from 1.1 for risk communication 705
 grants to 4.0 for code development. Ten of the grants in this 706
 stratum were for hazard mitigation plans, and nine were for risk 707
 communication activities. The standard deviation of benefit-cost 708
 ratio was omitted because the surrogate benefit methodology does 709
 not lend itself to this calculation. 710

Grants for Flood Process Mitigation Activities 711

Only six process grants for flood mitigation activities were evalu- 712
 ated. The small number reflects the fact that the majority of flood 713
 hazard process grants originally sampled were Project Impact 714
 grants, which were subsequently dropped from the benefit-cost 715
 analysis of FEMA grants study component because sufficient data 716
 for performing a complete analysis were lacking in the grant files. 717
 The average benefit-cost ratio for this stratum is 1.3, with little 718
 variation across individual cases. Five of the six process grants 719
 were mitigation plans and the other was for streamlining a build- 720
 ing permit process. Again, the standard deviation of benefit-cost 721
 ratio for process grants was omitted. 722

Summary of Results for Process Mitigation Activity Grants 723

A conservative estimate of the benefit-cost ratio for most process 724
 grants dealing with mitigation planning is about 1.4 (see MMC 725
 2005, Chap. 4). This estimate is based on the Mecklenburg 726
 (Canaan 2000) studies, the study by Taylor et al. (1991), and the 727
 URS Group (2001) report, which is most applicable to multihaz- 728
 ard planning grants. For grants for activities involving building 729
 codes a conservative estimate is higher than for multihazard plan- 730
 ning grants, at a value of approximately 4. This estimate is an 731
 average based on the lower end of benefit-cost ratios provided in 732
 the studies by Taylor et al. (1991), Porter et al. (2006), and Lom- 733
 bard (1995). The estimate is likely conservative because of the 734
 very wide range of potential benefit-cost ratios estimated for ac- 735
 tual adopted building codes and savings in property damage from 736
 hurricanes of different size categories, including a few very high 737
 benefit-cost ratios for building codes (Lombard 1995). With re- 738
 gard to a grant for seismic mapping, another estimate to confirm 739
 this range for the benefit-cost ratio is 1.3 based on the Bernknopf 740
 et al. (1997) study of the value of map information, which as- 741
 sumes that property value changes fully capitalize the hazard dis- 742
 closure effects via the housing market. 743

Grants for building code activities likely will have a larger 744
 benefit-cost ratio than grants for information/warning and hazard 745
 mitigation plan activities. If a grant is inexpensive, it is quite 746
 likely that its net benefits will be positive, based on the Litan et al. 747
 (1992) study of earthquake mitigation, which found average 748
 benefit-cost ratios of about 3. Therefore, any small grant for pro- 749
 cess activities that does not have negative consequences in ob- 750
 taining mitigation will only slightly raise costs and, therefore, 751
 only slightly reduce the benefit-cost ratios in this category. As 752
 Lombard (1995) notes, the benefit-cost ratio in some cases (e.g., 753
 smaller homes), and some hurricane categories (on a scale of 754
 1–5), could be very large. An example is a benefit-cost ratio of 38 755
 for anchorages for a Category 2 hurricane. Lombard’s ratios are 756
 based on actual costs of mitigation, not related to grants per se, 757
 and there is no way to know how the probability of adopting 758
 specific building codes is changed by the grant. 759

Based on logic and effectiveness found in other contexts 760
 (Golan et al. 2000), there is reason to believe that grants for 761
 process mitigation activities provide positive net benefits in many 762

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

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

^an.a.=not applicable because of estimation method used.

763 situations. Project mitigation activities in many cases would never
 764 take place if a process activity had not generated the initial plan
 765 or building code that led to implementation. A common sense
 766 conclusion is that when net benefits from mitigation in a particu-
 767 lar category, exclusive of a grant for process activities, are large
 768 then a small grant certainly cannot reduce the net benefits by
 769 much; hence, any grant in that category is likely to be positive.
 770 Several caveats are warranted. First, in the literature search, no
 771 studies were found that specifically and clearly estimated the ben-
 772 efits of a hazard mitigation process activity. To estimate process
 773 activity benefits would require knowledge of how the probability
 774 of decision makers adopting a mitigation strategy changed after
 775 implementation of a process activity. Possible key differences
 776 have been noted between radon risk communication and a natural
 777 hazard risk warning. In general, the information that is available,
 778 even for conventional natural hazards, largely pertains to benefits
 779 and costs for mitigation projects or mitigation costs in general,
 780 i.e., not related to any grant activity. Second, there is still not
 781 enough information in the literature on the effectiveness of pro-
 782 cess activities to induce adoption of a mitigation action to gener-
 783 alize in the above categories. Last, there is regional variation in
 784 rates of adoption of mitigation practices because of differences in
 785 conditions, experience, and perceptions (see the community stud-
 786 ies discussion in MMC 2005; Chap. 5).

Extrapolation of Sample Results to Population

787

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

$$B_j = \frac{C_j}{N_j} \sum_{i=1}^{N_j} \frac{b_i}{c_i} \tag{1}$$

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

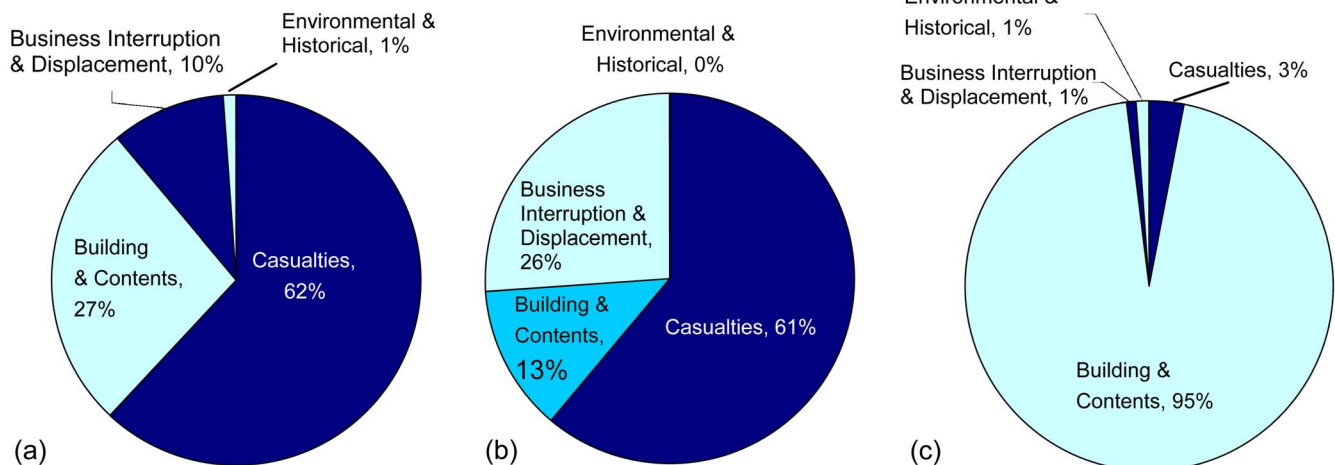


Fig. 1. Contribution to benefit-cost ratio by factor for: (a) earthquake; (b) wind; and (c) flood

Table 3. Summary of Benefits and Costs by Hazard

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

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

820 Breakdown of Results

821 The results are summarized by grants for each hazard type in
 822 Table 3, which shows that overall, mitigation grants for each haz-
 823 ard have benefit-cost ratios greater than one, with the grants for
 824 flood mitigation being the most cost-beneficial (BCR=5.0). Table
 825 4 summarizes the benefit-cost analysis results by major mitigation
 826 type. It shows that both project and process activities are cost
 827 beneficial, with projects having an average benefit-cost ratio of
 828 4.1, and processes having an average benefit-cost ratio of 2.0.
 829 Overall, flood grant benefits (both project and process) represent
 830 80% of the total FEMA grant benefits. Wind and earthquake ben-
 831 efits each represent approximately 10% of the total.

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

841 Deaths and Injuries

842 Table 5 highlights the reduction of casualties as a result of the
 843 mitigation activities conducted under the grants in the sample and
 844 for the entire population of grants. Because the NEMIS database
 845 does not include data on the number of people affected by each
 846 grant, it was necessary to estimate reduction in casualties for the
 847 population of grants using grant costs. Total reduced casualties

Table 4. Summary of Benefits and Costs by Mitigation Type

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

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

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

among the population of grants is estimated as the reduction 848
 among the sample grants times the ratio of population cost to 849
 sample cost. 850

Mitigation grants in the population of FEMA grants will pre- 851
 vent an estimated 4,699 injuries and 223 deaths over the assumed 852
 life of the mitigation activities, which in most cases is 50 years. 853
 As illustrated in Table 5, grants for wind mitigation activities will 854
 prevent the most injuries (1,790) and the most deaths (156). As 855
 with any casualty figures, these estimates require caution, as they 856
 are based on a scientifically sound methodology, but are difficult 857
 to validate because of limited available empirical data. The grants 858
 examined not only benefit society by reducing financial expendi- 859
 tures, but also, and equally as important, reduce associated stress 860
 and family interruption. While consideration was not able to be 861
 given to the financial benefit of these reductions, they are an 862
 important component of the benefit of mitigation. 863

Net Benefits to Society 864

The overall benefit to society for all 5,479 grants is approximately 865
 \$14.0 billion, and the cost to society is \$3.5 billion. The net ben- 866
 efit to society of FEMA-funded mitigation efforts is thus \$10.5 867
 billion, which includes the financial benefits and dollar-equivalent 868
 benefit of saving 223 lives and avoiding 4,699 nonfatal injuries. 869

Interpretation of Results 870

Benefit-cost ratios vary significantly across hazards. One major 871
 reason is that the type of avoided damage differs significantly 872
 between earthquakes, hurricanes, tornados, and floods. For ex- 873
 ample, 95% of flood benefits are attributable to avoided losses to 874
 structures and contents, and only 3% is for casualty reduction, as 875
 opposed to casualty reductions slightly over 60% each for the 876
 cases of earthquake and wind hazards. The cost effectiveness of 877
 measures to reduce property damage from frequent flooding is 878
 higher than that for reducing casualty in the wind and earthquake 879
 grants sampled in our study. This is in part because of the lower 880
 variability of factors affecting structures (which are of a fixed 881
 location, size, etc.) than of casualties (where occupancy rates vary 882
 by time of day), thereby making it harder to protect the latter. For 883
 example, mitigation grants to replace pendant lighting in schools 884
 provide potential protection but did yield actual benefits only for 885
 earthquakes that occur during hours when the buildings are occu- 886
 pied. In a similar vein, a higher proportion of wind mitigation 887
 grants is for the purpose of reducing the vulnerability of electric 888
 utilities to hurricane and tornado winds, than is the case for earth- 889
 quakes. The largest individual grant benefit-cost ratios found in 890
 our study stemmed from reduced business interruption associated 891
 with damage to utilities. 892

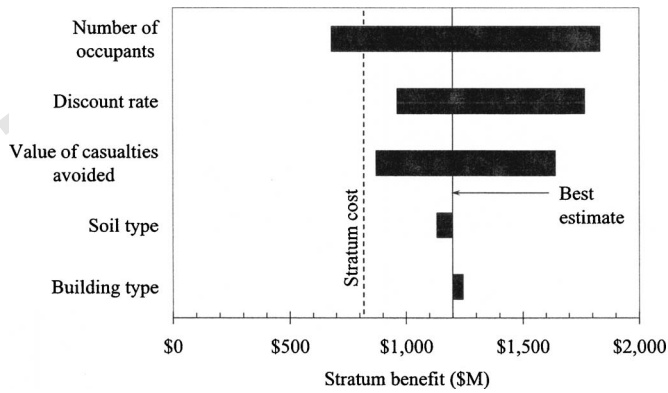


Fig. 2. Sensitivity of benefit to uncertainties (grants for earthquake project mitigation activities)

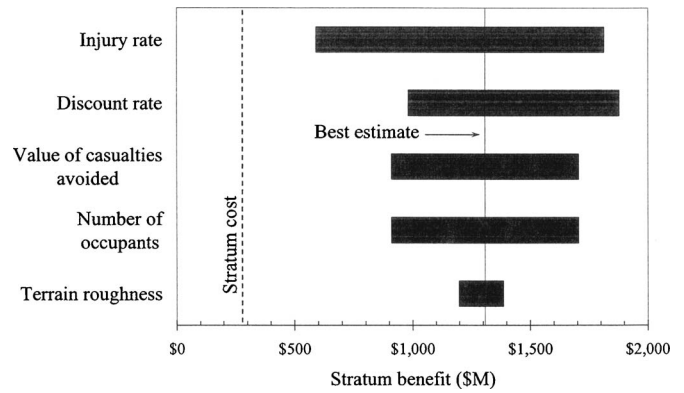


Fig. 3. Sensitivity of benefit to uncertainties (grants for wind project mitigation activities)

893 Flood mitigation grants have a higher probability of success,
 894 and hence a higher benefit-cost ratio because they pertain to prop-
 895 erties with known histories of vulnerability in the heart of flood-
 896 plains, and recurrence of floods in a given location is much more
 897 certain than for other hazards. Given that process mitigation
 898 grants have lower benefit-cost ratios than project mitigation
 899 grants across all hazard categories, the fact that process grants
 900 represented only 0.15% of total flood project mitigation benefits,
 901 in contrast to 1.2% of wind mitigation grant benefits, kept the
 902 flood process mitigation grants from pulling down the overall
 903 flood BCR as much as they did for overall wind benefit-cost ratio.
 904 When considering why the BCRs for earthquake mitigation
 905 are lower than flood and wind mitigation, one must consider
 906 policy emphases (i.e., California’s earthquake mitigation priorities
 907 and FEMA’s flood mitigation priorities) and hazard probabilities.
 908 Most of the sampled earthquake grants were from California,
 909 where the state’s priorities emphasized reducing casualties, and
 910 making schools and hospitals safer and more reliable. Local pri-
 911 orities emphasized retrofit of city-owned emergency facilities and
 912 administrative buildings. The bulk of earthquake grants went to
 913 school districts for nonstructural mitigation intended to reduce
 914 casualties, and government agencies for government-owned
 915 buildings, only a few grants had business interruption implica-
 916 tions. Because seismic codes with seismic provisions have been
 917 followed for decades in California, these buildings are not too
 918 vulnerable to the less intense earthquakes estimated to occur with
 919 the frequency associated with floods (within the 100-year recur-
 920 rence areas). Earthquake mitigation is motivated by concern for
 921 preventing casualties from large magnitude low probability earth-
 922 quakes, not smaller frequent earthquakes. Earthquake retrofit
 923 projects reduce, but do not eliminate vulnerability to these rare
 924 events, so the increment of avoided physical damage is small.
 925 This situation differs for flood mitigation, where many of the
 926 grants are to remove private structures from the 100-year or more
 927 frequent return hazard area (repetitive loss areas). Mitigation
 928 often eliminates flood damage except in the very large events, but
 929 our study placed less consideration on events that recurred less
 930 frequently than once in 100 year.
 931 Our study found BCRs for grant activities related to electric
 932 utility mitigation projects to be much higher for wind than for
 933 earthquake. However, this is due to the higher prevalence of pub-
 934 licly owned utilities in areas relatively more vulnerable to wind
 935 hazard than in high-risk earthquake zones (as well as the idiosyn-
 936 cratic nature of an earthquake project grant in our sample oriented
 937 toward life safety). However, potential BCRs of future mitigation

938 projects for public and private electric utilities are similar be- 938
 939 tween wind and earthquake. Any comparison between BCRs must 939
 940 also consider these policy decisions and background conditions, 940
 941 in order to avoid mistaken generalizations that some hazards and 941
 942 mitigation types will always produce higher BCRs. 942
 943 BCA focuses on the aggregates of benefits and costs, but their 943
 944 distribution is also important from a public policy standpoint (see, 944
 945 e.g., Rose and Kverndokk 1999). There are often large disparities 945
 946 in losses from natural hazards, with disadvantaged groups often 946
 947 bearing a disproportionate share, as dramatized most recently by 947
 948 the impacts of Hurricane Katrina. Thus, mitigation in general is 948
 949 likely to benefit lower income and other disadvantaged groups. 949
 950 Unfortunately, data were not available to evaluate the distribution 950
 951 of benefits across socioeconomic groups for grants in this study, 951
 952 and are generally not readily available for most mitigation activi- 952
 953 ties. 953

Sensitivity Analysis 954

955 Uncertainties in the loss-estimation procedure lead to uncertainty 955
 956 in the estimated benefit. For this reason, it is reasonable to ques- 956
 957 tion how robust the results are to these uncertainties, i.e., how 957
 958 confident can one be that benefits exceed cost? Sensitivity analy- 958
 959 ses were performed on the analysis parameters that were judged 959
 960 most likely to most strongly influence the results. Figs. 2–4 illus- 960
 961 trate how making different assumptions about each of these param- 961
 962 eters affects the total estimated benefit for those that revealed 962

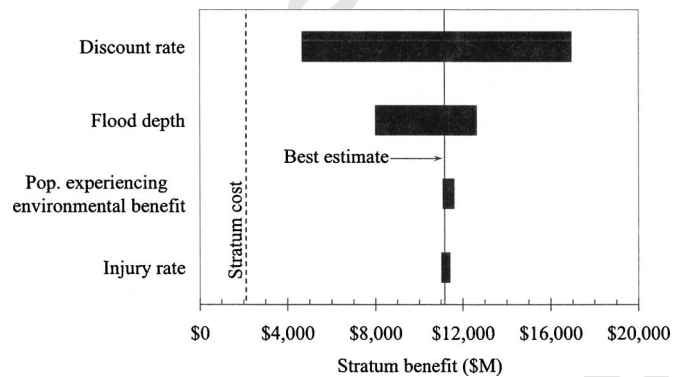


Fig. 4. Sensitivity of benefit to uncertainties (grants for flood project mitigation activities)

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

969 Each black bar in the diagram reflects what happens to the
970 total population estimated benefits for that hazard if one param-
971 eter (number of occupants, discount rate, etc.) is changed from a
972 lower-bound to an upper-bound value. A longer bar reflects
973 greater sensitivity of benefit to that parameter. Here, the “lower-
974 bound” and “upper-bound” values are estimates of the 4th and
975 96th percentile values of the parameter in question for reason
976 having to do with a subsequent mathematical procedure. In the
977 case of the discount rate, the values shown are for 0% (higher
978 benefit) and 7% (lower benefit). The parameters are sorted so that
979 the longest black bar—the one for the parameter to which the
980 benefit is most sensitive—is on top, the next most sensitive is
981 second from the top, etc. The resulting diagram resembles a tor-
982 nado in profile, and is called a tornado diagram.

983 The diagram does two things: first, it shows the conditions
984 under which benefit exceeds cost. For example, Fig. 2 shows that
985 benefit exceeds cost even if the discount rate is set to its upper
986 bound (7%). Second, the baseline benefit and the values of benefit
987 at the ends of the bars can be used to estimate the parameters of
988 a probability distribution of total nationwide benefit. These pa-
989 rameters include the mean and standard deviation of total benefit,
990 among others. To calculate them, a mathematical procedure called
991 an “unscented transform” was used (Julier and Uhlman 2002).
992 This procedure allows one to estimate the moments of a probabil-
993 ity distribution of an uncertain output variable that is itself a
994 deterministic function of one or more uncertain input variables. In
995 the present application, the total nationwide benefit was treated as
996 the output variable that is a function of the input uncertainties
997 shown in Fig. 2. The sample points used in the unscented trans-
998 form are the baseline benefit and the ends of the bars in Fig. 2.
999 Note that the unscented transform produces a slightly different
1000 expected value of benefit than the baseline figure.

1001 Results

1002 Grants for Earthquake Project Activities

1003 Results for earthquake project mitigation benefits are illustrated in
1004 Fig. 2. In the figure, the solid vertical line at \$1.2 billion reflects
1005 the baseline benefit for earthquake project grants; the dashed line
1006 at \$0.87 billion represents the cost of those grants. Total benefit is
1007 most strongly sensitive to number of occupants, then to discount
1008 rate, then to value of casualties. Notice that the only bar that
1009 crosses below the cost of mitigations is the first one, number of
1010 occupants. In all other cases, benefits exceed costs.

1011 Using the unscented transform, it was found that the expected
1012 value of benefit from earthquake mitigation grants is \$1.3 billion
1013 (approximately the same as the baseline figure of \$1.2 billion).
1014 The standard deviation of benefit is \$470 million. Assuming that
1015 benefit is lognormally distributed, the ± 1 SD bounds of benefit
1016 are \$850 million and \$1.7 billion. Benefit exceeds cost with 0.83
1017 probability. The expected value of benefit-cost ratio is 1.5, ap-
1018 proximately the same as the baseline value of 1.4.

1019 A word of caution regarding the comments about the probabil-
1020 ity that benefit exceeds cost. According to standard benefit-cost
1021 analysis, earthquake project grants are cost effective, because
1022 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 uncer-
tain parameters, earthquake projects are estimated to save \$1.40
in reduced future losses for every \$1 spent.

Grants for Wind Project Mitigation Activities

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

Grants for Flood Project Mitigation Activities

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

Other Sensitivity Analyses

Sensitivity analyses were not performed for direct business inter-
ruption for two reasons. First, direct business interruption esti-
mates 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 pro-
duction 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 ap-
plied, the small size of indirect business interruption in all cases
(except the few mitigation grants affecting utilities), and the nar-
row variation in this parameter.

Excess capacity is one of several sources of resilience Rose
(2004a) to disasters factored into this study (recall the discussion
in “Sampled Grants for Project Mitigation Activities”). Another is
the “recapture factor” (the ability to make up lost production at a
later date), which is automatically included in the HAZUS MH
direct economic loss module (DELM). This recapture factor was
also included in the HAZUS MH extension for utilities developed
in this study, and in fact the recapture factor for services was
increased in line with the study’s conservative assumptions. Other
aspects of resilience pertained to inventories, import of goods for
which there is a shortage, and export of surplus goods. These
were automatically computed in the HAZUS MH indirect eco-

1082 nomic loss module (IELM). Resilience effects were not separated
 1083 out, because that was not the focus of this study. HAZUS MH
 1084 default values were used for these parameters (inventories, im-
 1085 port, and export of goods) and sensitivity analyses were not un-
 1086 dertaken because HAZUS MH import and export resilience fac-
 1087 tors only affect indirect business interruption, which was
 1088 relatively minor, and because inventories were not a factor in
 1089 nearly all of the cases where direct business interruption was large
 1090 (e.g., electricity cannot be stored). It was assumed that hospital
 1091 inventories would not be significantly affected by most disasters,
 1092 given the tendency of hospitals to place priority on this feature
 1093 and to have emergency plans in place to meet shortages. This
 1094 results in a narrow range in possible inventory holdings.

1095 Combining Sampling Uncertainty and Modeling 1096 Uncertainty

1097 Since the total benefit of FEMA grants is uncertain, it is useful to
 1098 quantify and combine all important sources of uncertainty. This
 1099 information can then be used to calculate two interesting consid-
 1100 erations: (1) a probabilistic range for the total benefit of FEMA
 1101 grants for each hazard; and (2) the probability that the “true”
 1102 benefits exceed the cost. The uncertainty in total benefit of FEMA
 1103 grants results from two principle sources:

- 1104 1. *Sampling uncertainty.* Total benefits are uncertain because
 1105 they are estimated from a sample (a subset) of FEMA grants,
 1106 not the entire population of them. Here, sampling uncertainty
 1107 is quantified in Table 3, via the sample standard deviation of
 1108 the benefit-cost ratio.
- 1109 2. *Modeling uncertainty.* Total benefits are uncertain because a
 1110 mathematical model of benefits has been created and applied,
 1111 and that mathematical model has its own uncertain param-
 1112 eters. For this report, modeling uncertainty is quantified in
 1113 “Sample Results,” via the standard deviation of benefit.
 1114 As detailed in MMC (2005; Appendix R), these two sources of
 1115 uncertainty are combined to estimate overall uncertainty in ben-
 1116 efit of FEMA grants. The following two observations are made:
 1117 1. Modeling uncertainty dominates total uncertainty so a larger
 1118 sample would not significantly improve the accuracy of the
 1119 estimated benefits; and
 1120 2. The results reaffirm the observation that grants for project
 1121 mitigation activities produce benefits in excess of costs with
 1122 high probability for all three hazards.

1123 Conclusions

1124 Congress requested that an independent study determine savings
 1125 from FEMA-funded mitigation activities. In response, this study
 1126 determined that the present value discounted net benefits to soci-
 1127 ety from 5,479 FEMA grants between mid-1993 and mid-2003
 1128 for flood, wind, and earthquake hazard mitigation is \$10.5 billion.
 1129 The gross benefits are approximately \$14.0 billion, and the cost to
 1130 society is \$3.5 billion. The benefit-cost ratios for these grants
 1131 average 4.0. Thus, Americans benefited greatly from FEMA’s in-
 1132 vestment in mitigation.

1133 The benefits of mitigation include improved public safety. The
 1134 projects funded by the grants will prevent an estimated 4,699
 1135 injuries and 223 deaths over the assumed life of the mitigation
 1136 activities, which in most cases is 50 years. Also, another part of
 1137 the study involving mitigation activities in eight communities
 1138 confirmed the results from the statistical study of individual

grants and found that additional benefits also accrue, some of 1139
 which were not valued in monetary terms (MMC 2005, Chap. 7). 1140

The study results are robust and reliable. They were tested for 1141
 sensitivity to reasonable analytical variables. 1142

The results of this study have numerous implications, some of 1143
 which include: 1144

1. Federal investments in mitigation benefit society. Societal 1145
 benefits of grants made between 1993 and 2003 were four 1146
 times greater than the cost; 1147
2. The benefits from mitigation grants are greater than just the 1148
 benefits that can be measured and valued in monetary terms; 1149
3. Both project- and process-type mitigation activities have 1150
 benefit-cost ratios exceeding 1.0. However, project mitiga- 1151
 tion activities in many cases would never take place if a 1152
 process activity had not generated the initial plan or building 1153
 code that led to implementation; 1154
4. Deeper insight into the cost effectiveness of hazard mitiga- 1155
 tion project grants could be attained by developing and 1156
 implementing a formal procedure to assess the performance 1157
 of buildings and infrastructure after all types of disasters; and 1158
5. Although this study did not specifically assess the combined 1159
 benefits of mitigation activities across all hazards, the meth- 1160
 odology could be adapted to do so. This could help govern- 1161
 ment agencies responsible for providing mitigation to utilize 1162
 an even more cost-effective all-hazards mitigation strategy. 1163

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 munity Study investigation, headed by Elliott Mittler; and the 1171
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 the auspices of the Multihazard Mitigation Council (MMC) of the 1175
 National Institute of Building Sciences (NIBS), which was 1176
 charged by FEMA to conduct the necessary research requested by 1177
 Congress. In Phase I, MMC (2002) specified the parameters of 1178
 such a study with two parallel and interrelated components: a 1179
 nationwide statistical sample to assess the savings realized 1180
 through mitigation, and a community-based study to examine 1181
 standard benefits as well as effects of mitigation that might be 1182
 otherwise be difficult to quantify, such as additional mitigation 1183
 activities that result from but are not a part of FEMA-funded 1184
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 the Benefit-Cost Analysis of FEMA Mitigation Grants using the 1188
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 director, and Tom McLane served as project manager. The last 1191
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 provided valuable input into its implementation in the Phase II 1196
 Study, part of which is reported upon here. 1197

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

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

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

^aExtension refers to a method that builds on HAZUS MH with a similar and compatible approach.

^bNone of the sampled flood projects involved business interruption.

^cMeasured as part of business interruption.

^dAlso includes emergency services benefits.

^eReduced form refers to the use of component parts, such as functional relationships and data, from a HAZUS MH module.

^fOnly relevant to earthquakes.

1198 Appendix I. Benefit Estimation Methods

1199 Overview

1200 Table 6 summarizes the methods used for each hazard and benefit
1201 type (avoided loss). HAZUS MH, in various forms, was the pre-
1202 dominant method. “HAZUS MH extension” refers to methods
1203 developed expressly for this study to fill in a gap in the tool (e.g.,
1204 its application to determining the full range of direct business
1205 interruption losses from lifeline failures as well as indirect busi-
1206 ness interruption losses). “HAZUS MH reduced form” refers to
1207 the use of various data and functional relationships from HAZUS
1208 MH (e.g., data and damage functions relating to flooding). More
1209 details of these adaptations of HAZUS MH can be found in the
1210 appendices of MMC (2005).

1211 HAZUS MH

1212 HAZUS MH is built on an integrated GIS platform that estimates
1213 losses due to earthquake, flood, and hurricanes. The software pro-
1214 gram is composed of seven major interdependent modules. The
1215 connectivity between the modules is conceptualized by the flow
1216 diagram in Fig. 5. The following discussion provides a brief de-
1217 scription of each module; detailed technical descriptions can be
1218 found in the *HAZUS MH technical manuals* (NIBS and FEMA
1219 2003a, c, 2003b).

1220 Potential Hazards (1)

1221 The potential-hazards module estimates the expected intensities
1222 or hazard severities for three hazards: earthquake, flood, and hur-
1223 ricane. For earthquake, this would entail the estimation of ground
1224 motions and ground failure potential from landslides, liquefac-
1225 tion, and surface fault rupture. For flood, this involves the estima-
1226 tion of flood heights or depths. For hurricane, this entails the
1227 estimation of wind speeds. For a probabilistic analysis, the added
1228 element of frequency or probability of occurrence would be
1229 included.

Inventory Data (2) **1230**

A national-level exposure database is built into HAZUS MH, **1231**
 which allows the user to run a preliminary analysis without hav- **1232**
 ing to collect additional local information or data. The default **1233**
 database includes information on the general building stock, es- **1234**
 sential facilities, transportation systems, and utilities. The general **1235**
 building stock data are classified by occupancy (residential, com- **1236**
 mercial, industrial, etc.) and by model building type (structural **1237**
 system, material of construction, roof type, and height). The de- **1238**
 fault mapping schemes are state-specific for single-family dwell- **1239**
 ings and region-specific for all other occupancy types. In all **1240**
 cases, they are age and building-height specific. **1241**

Direct Damage (3) **1242**

This module estimates property damage for each of the four in- **1243**
 ventory groups (general building stock, essential facilities, trans- **1244**
 portation, and utilities), based on the level of exposure and the **1245**
 vulnerability of structures at different hazard intensity levels. **1246**

Induced Damage (4) **1247**

Induced damage is defined as the secondary consequence of a **1248**
 disaster event on property. Fire following an earthquake and ac- **1249**
 cumulation of debris are examples. **1250**

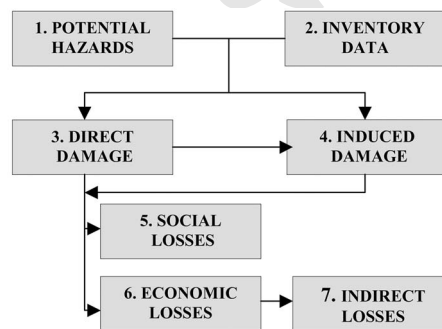


Fig. 5. HAZUS MH modules

1251 Societal Losses (5)

1252 Societal losses are estimated in terms of casualties, displaced
1253 households, and short-term shelter needs. The casualty model pro-
1254 vides estimates for four levels of casualties (minor injuries to
1255 deaths), for three times of day (2:00 a.m., 2:00 p.m., and 5:00
1256 p.m.), and for four population groups (residential, commercial,
1257 industrial, and commuting). The number of displaced households
1258 is estimated based on the number of structures that are uninhab-
1259 itable, which is in turn estimated by combining damage to the
1260 residential building stock with utility service outage relationships.

1261 Economic Losses (6)

1262 Direct economic losses are estimated in terms of structural and
1263 nonstructural damage, contents damage, costs of relocation,
1264 losses to business inventory, capital-related losses, wage and sal-
1265 ary income losses, and rental losses.

1266 Indirect Economic Losses (7)

1267 This module evaluates region-wide (“ripple”) and longer-term ef-
1268 fects on the regional economy from earthquake, flood, and wind
1269 losses. Estimates provided include changes in sales, income, and
1270 employment, by industrial sector.

1271 The various modules of the HAZUS MH software have been
1272 calibrated using existing literature and damage data from past
1273 events. For earthquake, two pilot studies were conducted several
1274 years ago for Boston and Portland, Ore., to further assess and
1275 validate the credibility of estimated losses. A similar testing and
1276 validation effort was conducted for flood and hurricane wind.

1277 Appendix II. Assumptions

1278 Following are the most significant assumptions of our analysis.
1279 They were necessitated by a combination of standard practices,
1280 data limitations, and computational manageability.

- 1281** 1. *Risk neutrality.* This is a standard assumption of benefit-cost
1282 analysis;
- 1283** 2. *Meaning of benefits and costs.* Benefits were taken as the
1284 present value of reduced future losses. Costs were taken as the
1285 expected present value of the cost to undertake a mitiga-
1286 tion measure. Some categories were ignored, such as facility
1287 operation and maintenance costs. Intangible (nonmarket)
1288 costs of mitigation could not be quantified;
- 1289** 3. *Implementation effectiveness.* We assume that each mitiga-
1290 tion activity is fully implemented at maximum effectiveness;
- 1291** 4. *Accuracy of HAZUS MH.* While its accuracy remains to be
1292 fully proven, HAZUS MH represents the only available na-
1293 tional standard multihazard loss-estimation tool. The com-
1294 plete HAZUS MH flood loss module was not ready for use,
1295 although its damage functions were used;
- 1296** 5. *HAZUS MH default values.* Several were used, most notably,
1297 relocation costs, repair duration, building recovery time,
1298 rental income, and recapture factor, import and export capa-
1299 bility, restoration of function, rebuilding pattern, and inven-
1300 tory demand and supply;
- 1301** 6. *Time value of money.* Future economic values were brought
1302 to present value at time-constant discount rates of 2%, and
1303 results were sensitivity tested to discount rates between 0 and
1304 7%;
- 1305** 7. *Inflation adjustment.* All dollar values of past costs were ad-
1306 justed to January 1, 2002, terms using the consumer price
1307 index;
- 1308** 8. *Planning period.* Property mitigations were assumed to be

- effective for 50 years for ordinary structures and 100 years **1309**
for important structures and infrastructure, regardless of **1310**
property age; **1311**
9. *Accuracy of FEMA data.* Data in the NEMIS and grant ap- **1312**
plications were assumed to be correct, subject to some lim- **1313**
ited quality control; **1314**
10. *Accurate soil data.* U.S. Geological Survey and California **1315**
Geologic Survey soil maps were assumed to be accurate; **1316**
11. *Value of avoided statistical deaths and injuries.* Avoided sta- **1317**
tistical deaths and injuries were valued using FHWA (1994) **1318**
figures, brought to 2002 constant dollars, but not time dis- **1319**
counted; **1320**
12. *Constant hazard.* Hazard levels were assumed to be time **1321**
invariant; **1322**
13. *Direct business interruption.* These losses were not applied **1323**
to residences; **1324**
14. *Indirect business interruption.* These losses were not applied **1325**
to residences, schools, libraries, hospitals, and fire houses; **1326**
15. *Excess capacity.* The unemployment rate was used as a **1327**
proxy; **1328**
16. *Boundaries of regional economies for indirect business inter- **1329***
ruption loss estimation. Regional economies were delineated **1330**
by the boundaries of the county or county group incurring **1331**
physical damage, although most economic regions, or trading **1332**
areas, do not conform precisely to political boundaries; **1333**
17. *Regional input-output (I-O) tables.* The HAZUS MH I-O al- **1334**
gorithm is superior to standard I-O formulations, but retains **1335**
the limitations of the lack of input substitution and the ab- **1336**
sence of the explicit role of prices; and **1337**
18. *No interaction between grants.* The analysis assumed no in- **1338**
teraction between mitigation efforts. **1339**

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