Chapter 2
PRINCIPLES AND DEFINITIONS

This chapter discusses the guiding principles of this study, describes the key methods that define its scope and depth, and presents important definitions and delineations that help to connect its different parts. The discussion helps lay the foundation for more detailed and complex summaries of the approach to assessing mitigation benefits. The reader should note that, while the discussions are general, some parts may apply more to a particular study component. For example, the discussion on case study principles is designed to frame the approach used in the community studies. Similarly, the section on synergistic activities focuses on key concepts used in the community study analysis to define the extended benefits of mitigation. All other discussions apply to both study components.

2.1 Benefit-Cost Analysis

A benefit-cost analysis requires that hazard mitigation costs and hazard losses be measured in terms of the value of all resources used (or destroyed) and at prices that represent their efficient allocation ─ not necessarily at market prices, which often do not account for inefficiencies or may not even exist in cases such as environmental resources (Boardman et al., 1996). In addition, transfer payments (e.g., taxes and subsidies) should not be included because they do not represent the use of resources, but rather a shift of funds from one entity to another. This method avoids double-counting and covers all resources, including nonmarket resources (Ganderton, 2004). In practice, standard accounting categories, such as asset purchase cost and lost sales, represent proxies for the ideal resource valuation (efficiency prices) because of limitations of measurement.

To complete a benefit-cost analysis, it is necessary to estimate all costs and all benefits. The cost side is usually the straightforward assessment of capital expenditures, and operation and maintenance expenses (where applicable). Benefits, or avoided losses from hazards, are much more difficult to assess because they are not limited to a single structure or moment in time and are highly uncertain over the short term. Accordingly, elaborate methods (discussed in the following sections) have been developed to estimate these benefits by first estimating the various categories of losses from hazards in the absence of, and in the presence of, mitigation. Two complications arise in estimating the future benefits of hazard mitigation. First is the need to discount them to a present value so that benefits accruing at different times can be made comparable. (An exception is that it is considered inappropriate to discount the economic value of avoiding future statistical deaths and nonfatal injuries. See Section 4.2.2.3.) Second is the need to express them in probabilistic terms (the number of times something will probably occur over the range of possible occurrences) to capture their uncertain frequency of occurrence and magnitude.

Benefit-cost analysis is widely used by the federal government. It was first made a requirement in the Flood Control Act of 1936 where Congress stipulated that the U.S. Army Corps of Engineers could only undertake flood control projects if the benefits of the projects exceeded their costs. Today, a benefit-cost analysis is required before many public projects or initiatives can be approved, including FEMA hazard mitigation grants. Several government documents specify formal rules and procedures for undertaking benefit-cost analyses (U.S. Government Accountability Office, 2002; Office of Management and Budget, 1992). Benefit-cost analysis methodologies have been refined by economists, other social scientists, scientists, engineers, and ethicists for over 60 years. Contentious issues, such as discounting, have been resolved by National Academy of Science panels.

FEMA follows established benefit-cost analysis practices, including the publication of its own guideline documents and the circulation of illustrative examples (e.g., NIBS and FEMA, 2003a; 2003b). The FEMA mitigation grant application process requires completion of a benefit-cost analysis. Approval hinges to a great extent on demonstration of positive net benefits, which is equivalent to a benefit-cost ratio exceeding 1.

The benefit-cost analyses in FEMA grant application files provide important information. However, not all of it could be used in this study for a variety of reasons including the following:

1. Because this study is intended to be an independent assessment, benefit-cost ratios in FEMA grant files were not used or validated. However, the basic data from the grant application files on the characteristics of structures and mitigation projects were used to estimate benefits.
2. The benefit-cost analyses in the FEMA grant applications examined typically did not include a wide range of benefits, especially those difficult to quantify (e.g., avoidance of indirect business interruption, environmental damage, and societal impacts). This study develops new methods to quantify such additional benefits.

This study does, however, use mitigation cost data from FEMA files. The first approximation to cost is the FEMA grant allocation, a matter of public record and a definite expenditure. This must, however, be adjusted for any significant transfer payments (e.g., taxes). It also should include any matching funds from other government entities or the private sector used to carry out the mitigation activity.

One important issue was the selection of an appropriate discount rate. The real rate used for discounting is based on market interest rates. The base case real discount rate used is 2 percent, the same rate that is recommended by the Congressional Budget Office (CBO) (Congressional Budget Office, 1998). This rate is based on a CBO estimate of the long-term cost of borrowing for the federal government and is generally considered a conservative estimate of the long-term real market risk-free interest rate. The Office of Management and Budget (OMB) recommends that the real rate should be based on the rate of return to private investment (Office of Management and Budget, 1992). The sensitivity tests conducted for this study were performed using 0 percent as a lower bound and 7 percent as an upper bound. A 7 percent rate approximates the marginal pretax rate of return on an average investment in the private sector in recent years. This rate is generally considered to be an upper bound for federal projects because the rate of return to public-sector projects is typically assumed to be lower than private-sector projects.

Another important issue in the calculation of benefits is the selection of the effective life of a mitigation effort, which is used to calculate the present value of avoided future losses. Consistent with common practice in the new design or rehabilitation of ordinary (non-essential or hazardous) buildings, the present study applies a 50-year effective life to mitigation efforts for ordinary buildings; a 100-year effective life is assumed for lifeline facilities.

2.1.1 Measures of Costs

The costs of hazard mitigation are all the resources used — not just the explicit "out-of-pocket" expenditures on labor, capital, materials, and services but also more subtle categories. The latter include implicit, or "opportunity costs" that refer to the use of inputs (e.g., donation of labor time, the carrying cost of capital) which may not have been charged to the mitigation activity but could have been productive elsewhere. The value of the foregone opportunity represents a type of implicit cost. Examples are government administrative costs and the value of non-priced environmental services. Environmental impacts can be either positive or negative (e.g., whether a wetland was destroyed in the course of building a drainage project or created by rezoning land).

There are also indirect costs and spillover effects of mitigation. An example of the latter is a change in real estate values, again possibly either positive or negative. Because nearly all of the mitigation grants analyzed applied to individual structures or a small cluster of private residences, spillover effects are assumed to be negligible, at least in the benefit-cost analysis of FEMA mitigation grants. An additional consideration is "ripple effects" of mitigation activities. These represent the additional jobs and income generated because of backward and forward economic linkages of the construction or operation of a mitigation project or process. Because of the controversy over whether to treat this category as a cost or a benefit and because of an Office of Management and Budget (1992) stricture against including it in official federal government benefit-cost analyses, this category also is omitted from the benefit-cost analysis of FEMA mitigation grants. This effect, however, is addressed (to a certain extent) in the community studies (Section 2.5.2, Synergistic Activities).

Independent estimates of the costs of administering FEMA grants could not be obtained, nor could estimates of the savings of reduced costs of administering post-disaster recovery because of mitigation. The omission of these two administrative cost categories is unlikely to have a significant effect on the *net* benefit calculations.

The primary approach to cost estimation involved use of entries from the National Emergency Management Information System (NEMIS) database on basic project and process costs. These cost entries are entered into NEMIS from grant applications and were considered to be reliable primary data for this study. On the other hand, estimation of nonmarket costs is based on the data-transfer methods that involve applying empirical results from related contexts to individual project and process grants in the sample.

In summary, the following hazard mitigation cost categories addressed in this study are:

1. Cost of project mitigation activities (e.g., building retrofit, bridge improvement, equipment tie-down, buyouts);

2. Cost of process mitigation activities (e.g., education, community organization to deal with hazards, vulnerability analysis); and
3. Nonmarket costs (e.g., effects on wetlands or historic sites).

2.1.2 Measures of Benefits

The benefits of hazard mitigation are the avoided losses that would have occurred if the mitigation activity had not been implemented. It is important at the outset to note two key differences between mitigation costs and benefits. Mitigation costs are incurred primarily during a short period, such as during construction, and they are relatively certain. The only exception pertains to operating costs and maintenance costs, but these costs are usually relatively minor in comparison to construction costs. Mitigation benefits, however, accrue over the useful life of the project or process activity and are highly uncertain over the short termbecause they are usually realized only if natural hazard events occur. At best, the expected value of benefits of mitigation measures currently in place can only be approximated by multiplying the potential total benefits by the probability distribution of hazard events. In addition, benefits must be discounted to present value terms to account for the time value of money.

The various categories of hazard mitigation benefits addressed in this report are:

1. Reduced direct property damage (e.g., buildings, contents, bridges, pipelines);
2. Reduced direct business interruption loss (e.g., damaged industrial, commercial, and retail facilities);
3. Reduced indirect business interruption loss (e.g., ordinary economic “ripple” effects);
4. Reduced (nonmarket) environmental damage (e.g., wetlands, parks, wildlife);
5. Reduced other nonmarket damage (e.g., historic sites);
6. Reduced societal losses (casualties, homelessness); and
7. Reduced need for emergency response (e.g., ambulance service, fire protection).

The standard loss category, direct property damage, is almost always reported in the aftermath of a natural disaster. Some of the other categories, such as direct and indirect business interruption losses, have been estimated more frequently in recent years. However, other categories, such as environmental damage and societal losses, have rarely been estimated, with the exception of casualty losses. The absence of estimates is due not to lack of legitimacy but rather to lack of data.

2.2 Loss Estimation Modeling

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

Loss estimation methodologies are now vital parts of many hazard mitigation studies. They are typically used to forecast the potential impacts of different hazard scenarios (typically used for planning), to project losses in an actual event (when used in conjunction with near real-time sensor systems, such as the ShakeMap system deployed by the U.S. Geological Survey), and to assess the benefits of a mitigation activity such as structural retrofit. A National Research Council (NRC) report, *Impacts of Natural Disasters* (NRC Committee on Assessing the Costs of Natural Disasters, 1999), also discusses the importance of relying on loss estimation modeling as a means of tracking and monitoring the costs of natural disasters. Because current government accounting systems are inadequate when it comes to totaling the costs of a disaster, the NRC report suggests that loss estimation modeling could provide surrogate means of tracking these costs.

FEMA has recognized the value of loss estimation modeling as a key hazard mitigation tool. In 1992, FEMA began a major effort (which continues today) to develop standardized loss estimation models that could be used by nontechnical hazard specialists. The resulting tool, the software program called HAZUS®MH, currently addresses earthquake, flood, and wind. It was used extensively in this study as discussed in Section 4.2.

2.2.1 Basic Components

To fully understand the loss estimation process, it is important to recognize the basic components of the mathematical model used to estimate loss (referred to here as the loss model). Regardless of the hazard being analyzed, a loss estimation model will consist of three basic components:

1. A hazard model that characterizes the likelihood and severity of the hazard;
2. An exposure model that quantifies the assets at risk in the area affected by the hazard; and
3. A vulnerability model that relates the damage potential of various assets to varying hazard levels.

Characterizing the hazard often involves the use of statistical or probabilistic models. Generally, an analyst is interested in two aspects of hazard: how frequently will the hazard occur over a designated period of time and what is the greatest intensity event that can be expected over a period of time. Probabilistic models that consider the relative frequency of past events are generally employed to determine frequency. For some hazards, this assessment may be easy; for hazards that occur only infrequently, this may be the most complex task of the entire loss estimation process.

Assessing the degree of exposure also is complex. Exposure applies to characterizing what is at risk — for example, the number of buildings, the amount of infrastructure within a region, or the number of people exposed to the hazard. In addition, quantification of exposed assets includes a characterization that often requires a definition or assignment of structural types and values.

Ironically, this component is often the most unsubstantiated part of the model. Although it has the potential for being 100 percent reliable, it generally relies on crude approximations because of the overwhelming resources needed to develop an accurate representation. In the present application, the nature of the facilities whose risk has been mitigated is crucial information, because costs and benefits are calculated largely based on specific projects, rather than on the nature of the general building stock.

The last major component is the vulnerability model. Often referred to as a fragility or damage function, this model directly relates the amount of damage or functionality expected to the level of hazard (or intensity) experienced. Significant research has been conducted in developing facility-specific functions for buildings and lifeline components. In many cases, the uncertainty or variability associated with these models is expressed in statistical (e.g., standard deviations) or probabilistic terms.

To complete a credible loss assessment, other modules or elements are needed. This procedure begins with translating physical property damage into dollar loss. Certainly, the value of the damaged facility is a key part of determining the eventual cost of repairs. For many facilities, however, the cost of downtime translated into lost production is also a major element of expected loss. The role of these other factors is discussed in the next section.

2.2.2 HAZUS®MH

HAZUS®MH is built on an integrated GIS platform that estimates losses due to earthquake, flood, and wind events. The software program is composed of seven major interdependent modules. The connectivity between the modules is conceptualized by the flow diagram in Figure 2-1. The following discussion provides a brief description of each module; detailed technical descriptions can be found in the HAZUS®MH Technical Manuals (NIBS and FEMA, 2003a, 2003b, 2003c).

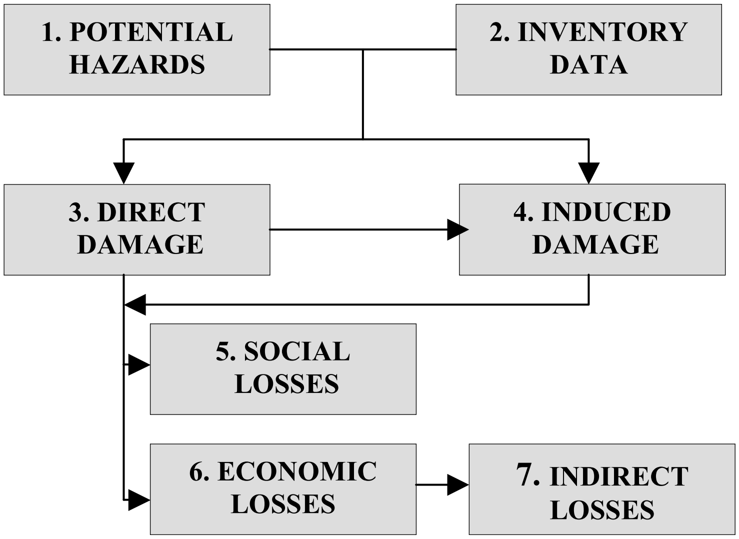

Figure 2-1 HAZUS®MH modules.

Potential Hazards (1) ─ The potential hazard module estimates the expected intensities or hazard severities for three hazards: earthquake, flood, and wind. For earthquake, this would entail the estimation of ground motions and ground failure potential from landslides, liquefaction, and surface fault rupture. For flood, this involves the estimation of flood heights or depths. For wind, this entails the estimation of wind speeds and wind-born debris. For a probabilistic analysis, the added element of frequency or probability of occurrence would be included.

Inventory Data (2) ─ A national-level exposure database of the built environment provided with HAZUS®MH allows the user to run a preliminary analysis without collecting additional local information or data. The default database includes information on the general building stock, essential facilities, transportation systems, and utilities. The general building stock data are classified by occupancy (residential, commercial, industrial, etc.) and by model building type (structural system, material of construction, roof type, and height). The provided mapping schemes are state-specific for single-family dwellings and region-specific for all other occupancy types. In all cases, they are age and building-height specific.

Direct Damage (3) ─ This module estimates property damage for each of the four inventory groups (general building stock, essential facilities, transportation, and utilities), based on the level of exposure and the vulnerability of structures at different hazard intensity levels.

Induced Damage (4) ─ Induced damage is defined as the secondary consequence of a disaster event on property. Fire following an earthquake and accumulation of debris are examples.

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

Economic Losses (6) ─ Direct economic losses are estimated in terms of structural and nonstructural damage, contents damage, costs of relocation, losses to business inventory, capital-related losses, wage and salary income losses, and rental losses.

Indirect Economic Losses (7) ─ This module evaluates region-wide (“ripple”) and longer-term effects on the regional economy from earthquake, flood, and wind losses. Estimates provided include changes in sales, income, and employment by sector (i.e., commercial, industrial, retail).

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

2.3 Benefit Transfer Methods

Not all mitigation measures evaluated in this study can be analyzed using traditional evaluation methods. Thus, an alternative approach for assessing mitigation benefits was needed. For environmental and historic building benefits, a feasible approach for measuring the benefits of hazard mitigation is the benefit transfer approach (Brookshire and Neill, 1992; Bergstrom and DeCivita, 1999). The approach was developed for situations in which the time and/or money costs of primary data collection are prohibitive. In this approach, environmental benefit estimates from other case studies are spatially and/or temporally transferred to the policy case study.

The benefit transfer approach can be used to quickly adapt benefit estimates from one case study to another and to develop those estimates around the particular parameters of the case study of interest. Benefit transfer is also increasingly being applied to estimating many categories of public policy benefits (ranging from economic to societal), not just the environmental aspects. There are several types of benefit transfer. For decades, economists have used the benefit estimate transfer approach in which researchers obtain a benefit estimate from a similar study conducted elsewhere and use it for a current policy analysis case study (e.g., Luken, Johnson, and Kibler, 1992). This study relies predominately on standard applications of benefit estimate transfer. The application of this approach to estimating the benefits of grants for process mitigation activities, however, stretches this method to its limits because there are no studies that measure the benefits of process activities. Studies of the implementation of process activities in related areas (e.g., radon risk communication) were used instead. Hence, this modified application is referred to as a surrogate benefit approach.

More recently, benefit function transfer and meta-analysis function transfer have been developed in an attempt to transfer benefits more accurately. Benefit function transfer uses a statistical model of benefits developed at the original study site to estimate benefits at the subsequent policy site application (e.g., Loomis, 1992). Characteristics from the policy site are substituted into the model from the study site to tailor benefit estimates for the policy site. Benefit function transfer is generally preferred to benefit estimate transfer but was determined to be too cumbersome for use in this study.

Meta-analysis is a general term for any methodology that summarizes results from several studies. Benefit estimates gathered from several studies serve as the dependent variable in regression analysis, and characteristics of the individual studies (e.g., water quality, type of survey methodology) serve as the independent variables (e.g., Rosenberger and Loomis, 2000). Meta-analysis functions were used in this study when available.

2.4 Case Study Principles

Case studies were employed to explore more fully the impact of hazard mitigation activities in a single community. The methods employed in the community studies followed traditional case study principles best expressed in U.S. Government Accountability Office (1990) and Yin (2003). They were selected to meet the independent study's goals and to address four tests commonly used to establish the quality of empirical social research. The tests, according to Yin (2003), are:

1. Construct validity (to establish correct operational measures for the concepts being studied);
2. Internal validity (to establish a causal relationship, whereby certain conditions are shown to lead to other conditions, as distinguished from spurious relationships);
3. External validity (to establish the domain to which a study's findings can be generalized); and
4. Reliability (to demonstrate that the operations of a study (e.g., such as the data collection procedures) can be repeated with the same results.

To meet these tests and the study's goals, the following techniques were used:

1. Purposive sampling ─ Communities were selected because they had received numerous FEMA hazard mitigation grants and the sum of their grants exceeded $500,000. Other selection criteria included geographical disparity and instances of earthquake, flood, and wind grants; they were not chosen because they might be considered best or worse cases, typical communities, or have special characteristics.
2. Reliability ─ Use of a case study protocol; development of a case study database.
3. Measurement or construct validity ─ Multiple sources of evidence were used (document collection, structured telephone interviews, open-ended on-site interviews, archival research) and a chain of evidence was established.
4. Data analysis or internal validity ─ Triangulation (comparison of multiple, independent sources of evidence before reaching conclusions); ordering information chronologically for time series analysis, rival explanations (developing alternative interpretations of findings and testing through search of confirming and non-confirming information until one hypothesis is confirmed and the others ruled out); plausibility after completely considering all evidence.
5. Handling multiple-site data sets (internal and external validity) ─ Matrices of categories related to the evaluation questions; flow charts listing critical decisions to illustrate each site and to use for comparisons; use of nonquantitative time series analysis for explanation building.

2.5 Definitions

In the conduct of this study, there are several key concepts that help to establish the scope and depth of the analysis. These are discussed below.

2.5.1 Process and Project Activities

An important definitional distinction in this study refers to "project" mitigation and "process" mitigation. As indicated earlier, project activities include physical measures to avoid or reduce damage resulting from disasters. Typically they involve elevating, acquiring, and/or relocating buildings, lifelines or other structures threatened by floods; strengthening buildings and lifelines to resist earthquake or wind forces; and improving drainage and land conditions (MMC, 2002). Process activities lead to policies, practices, and projects that reduce risk. These efforts typically focus on assessing hazards, vulnerability and risk; conducting planning to identify projects, policies, and practices and set priorities; educating decision-makers, and building constituencies; and facilitating the selection, design, funding, and construction of projects (MMC, 2002).

Because of the wide disparity in the types of studies that fall under each category, different evaluation approaches were used in the assessment of benefits. For most project activities, it was possible to use some type of quantitative method or tool (e.g., HAZUS®MH) to determine benefits. For process activities, benefit transfer methods were a key component in the assessment of mitigation benefits. Chapter 4 discusses in detail the various methods used to quantify mitigation benefits for both project and process activities.

2.5.2 Synergistic Activities

One potential benefit of a FEMA grant is that a community may be able to use it as seed money or otherwise leverage the grant funds to expand existing and/or to develop new mitigation programs. A FEMA mitigation grant also may lead to increased economic activities. However, communities may develop mitigation programs without FEMA influence. During community studies, some activities were found that were heavily influenced by the FEMA-funded grants and others were not − they were the result of other community processes. Thus, a scheme to categorize community activities that follow FEMA project or process grants was developed.

Synergistic activities are activities or effects, which reduce risks (or increase benefits of risk-reduction activities) from floods, earthquakes, and severe winds that follow or accompany the award of FEMA grants for project or process mitigation activities or the strong expectation that a grant would be awarded. These activities are not funded by FEMA and can take the form of spin-off activities, collateral activities, or spillover effects.

Spin-off activities are synergistic mitigation activities that directly (an action that would not otherwise have taken place) or indirectly (accelerated timing of an action that would have taken place eventually) result from or are enabled by FEMA hazard mitigation grant support, but which were not directly funded by FEMA. Collateral risk-reduction activities are activities that are not spin-off activities because FEMA hazard mitigation grant support had no significant impact on their content or timing. Spillover effects of mitigation include direct and indirect increases in economic activity or value of assets in the more conventional use of the terms direct (i.e., increase in business activity of new or revitalized enterprises or increase in property value) and associated indirect (i.e., ripple effects).

To determine if a community activity was a spin-off activity, it was asked whether there was a high chance that the activity in question was financed or supported because FEMA provided support (or was strongly expected to provide support) for another process or project. If a preponderance of evidence from telephone interviewees, face-to-face interviewees, and contemporary documents indicated that the answer was “yes,” then the activity in question was categorized as a spin-off activity. An example of a spin-off activity occurred in Jefferson County, Alabama, where following the implementation of a FEMA grant to buy out substantially damaged houses after a flood, the county council passed a regulation that mandates that the county set aside $2M annually for the specific purpose of removing houses from the floodplain. In this situation, the houses purchased from the FEMA grants funds were the first that the county removed, and both interviewees and documents indicated that the subsequent regulation was a direct result of the FEMA grant.

If the answer to the above question was “no,” it was asked whether the FEMA grant accelerated the activity in question. If the answer was “yes,” the activity in question was categorized as a spin-off activity. If the answer was “no,” the activity in question could not be a spin-off activity, but could still be a collateral activity.