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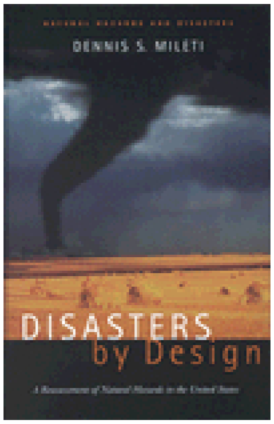

Disasters by Design: A Reassessment of Natural Hazards in the United States

by Dennis Mileti, A Joseph Henry Press book

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CHAPTER SIX

Tools for Sustainable Hazards Mitigation

Of the many techniques for coping with natural hazards and disasters that people have attempted to use, the five categories summarized in this chapter have proven over the past two decades to be the most useful for minimizing and/or redistributing losses and reducing social and economic disruption. Each of these mitigation tools (or adjustments as they were labeled in the first assessment)—land-use planning, building codes, insurance, engineering, and warnings—is supported by its own body of research, disciplines, experts, and government and private-sector management structure. These five mitigation tools are reviewed, and knowledge about them is summarized in this chapter. Also discussed are their potential roles and contributions to sustainable hazards mitigation. Absent from this chapter are discussions of disaster preparedness, response, and recovery, which are addressed in Chapter 7.

LAND-USE PLANNING AND MANAGEMENT

No single approach to bringing sustainable hazards mitigation into existence shows more promise at this time than increased use of sound and equitable land-use management. Many political, social, and economic forces conspire to promote development and redevelopment patterns that set the stage for future catastrophes. However, by planning for and managing land use to accomplish sustainable hazards mitigation, disasters—though not wholly eliminated—can be reduced to a scale that can be borne by the governments, communities, individuals, and businesses exposed to them.

Land-use planning, environmental protection, hazards mitigation, and sustainable communities are integrally related concepts with a similar vision—communities where people and property are kept out of harm's way from natural disasters, where the mitigative qualities of natural environmental systems are maintained, and where development is designed to be resilient in the face of natural forces. The landscapes of sustainable communities incorporate compact, higher-density development and more efficient use of land and space; greater emphasis on trees, parks, and open space; redevelopment of underutilized urban areas and infill development; public transit; mixed-use environments that are more amenable to walking and less dependent on automobiles; energy and resource conservation; renewable energy; and minimizing waste and pollution. Increasingly, community resiliency to natural disasters is being added to this list (see Berke, 1995).

Comprehensive Local Land-Use Plans

Local governments have many land-use management tools at their disposal for averting disaster losses and increasing community sustainability: building standards, development regulations, critical and public facilities policies, land and property acquisition, taxation and fiscal policies, planning processes, and information dissemination. Communities must decide which combination of measures will be effective, efficient, equitable, and feasible for them. An integrated, comprehensive community plan ties hazards mitigation, land use, and environmental, social, and economic interests together and lays out guidelines for when and how these tools are to be used. With the right mix of land-use management measures, local governments can reduce disaster losses while accomplishing environmental and other community goals.

Recent studies in Australia, New Zealand, and the United States have documented a number of benefits that follow when governments plan before they act. First, by providing information about the location and nature of various hazards, plans ensure that the limitations of hazard-prone areas are understood by policymakers, potential investors, and community residents. Second, by indicating the most appropriate uses of land in a community (and showing that hazardous areas do not always have to be used more intensively for communities to realize economic and other development objectives), plans make it possible for communities to consider and, where economically efficient, actually adopt restrictions on building in hazardous areas. Third, good land-use plans help educate the public, and this education, in turn, increases demand for action. Also, education used in concert with regulation is likely to be more effective than regulation alone (see Burby and May, 1997; May et al., 1996).

With a long-range, comprehensive, sustainability-oriented plan, a community can coordinate multiple issues, goals, and policies effectively. Local land-use plans should (1) be made before disasters occur (although better late than never); (2) be oriented toward the long-term future; (3) be focused on systems, as well as parts (ecosystems and cumulative effects vs. small areas and individual disasters); (4) include all sectors of society in the decisionmaking process; (5) begin by assessing hazards and characteristics of the community; (6) determine values, goals, and objectives; (7) adopt unambiguous plans and policies; (8) have provisions to monitor and evaluate the effectiveness of the policy; and (9) be flexible enough to change with time. As an illustration, among the sustainable mitigation components of a good comprehensive plan would be the following:

- *Hazard identification*: magnitude, location, and probability of a disaster.
- *Impact assessment*: what populations and properties are exposed to hazards, and the likely damage in a disaster.
- *Loss estimation*: the quantitative probability of damage, injuries, and cost in a given area over a specified time.
- *Carrying-capacity assessment*: the maximum load (population × per-capita impact) that can safely and persistently be imposed on the local environment by society without reducing the ability of the environment to support such a community in the future.
- *Built-out analysis*: the maximum level for the buildings and infrastructure given the character of the local social and environmental systems.
- *Ecological footprint analysis*: an estimate of the land and water area needed to support local consumption and development practices.

- *Assessment of sustainability indicators*: Many communities (e.g., Boulder, Seattle, Chattanooga, Tallahassee) have identified and measured such indicators as education, the economy, public safety, the natural environment, health, the social environment, politics, culture, and mobility.
- *Environmental impact statement*: Such a statement should always include an analysis of natural hazards.

Federal and State Policies

If local governments are to prepare and follow through with land-use planning for hazard mitigation, experience suggests that nothing short of strong mandates backed by commitment and effort by the federal government and states will suffice to bring it about. Without them most local governments will continue with business as usual. A few innovative jurisdictions—those with extraordinary local leadership and those that have suffered severe losses in the past—will plan for and manage land use in hazardous areas. However, most will not. Hazard mitigation requires a partnership. The actual planning and conduct of programs must occur at the local level, but a great deal of the impetus must come from above.

At present there is no overarching federal policy that governs land use and development in hazard-prone areas. Instead of a holistic approach, there are pieces, including over 50 federal laws and executive orders that relate to hazards management. Federal and state governments seem unwilling to embrace direct land-use management, yet they send local governments conflicting signals about exposure to hazards. Policies advocate risk reduction and transfer (standards, insurance, relief, etc.) rather than risk assumption and elimination. While such policies are appropriate in some cases, they also have created problems. Uniform standards disregard the fact that in some locales it is appropriate to assume the risk of developing hazardous areas. The focus of and subsidies built into federal insurance and relief programs probably help account for the massive increase in development in hazard-prone regions (see Burby and French, 1985; Beatley et al., 1994; Platt, 1987). The assurance of federal assistance after a repeat disaster creates a "moral hazard"[1] by lowering the incentive to avoid risk. Finally, federal policies

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[1] The term "moral hazard" is used to describe a situation in which one of the parties to an agreement has an incentive, after the agreement is made, to act in a manner that benefits

arguably have lessened the chances that hazard-prone development will be exposed to short-term losses (e.g., from a 100-year storm), while allowing the potential for greater losses from disasters with longer return frequencies to grow.

The federal and state focus on risk reduction and risk transfer, besides increasing exposure to hazard, has effectively shifted liability for the occupation of hazardous areas to Washington and to a lesser degree to the state capitols, thus relieving local governments of their traditional responsibility for managing these areas. The federal and state governments' top-down approach to dealing with local stakeholders has done little to foster the "local involvement, responsibility, and accountability" called for in the most recent comprehensive review of federal policy (Interagency Floodplain Management Review Committee, 1994, p. 82).

Also, because governmental institutions are disjointed and disaster policies are not integrated into general land-use policies, a host of other nondisaster-related federal policies limit the ability of local governments to use land-use management to reduce exposure to hazards. For example, increased exposure of people and property to flooding has been abetted by federal financing of highway construction, sewers, and other infrastructure that increase development potential in flood-prone areas while also reducing development costs. Some progress has been achieved in integrating hazards considerations into local planning and land-use management, however, particularly in states that have comprehensive growth management programs.

Barriers to Local Action

In addition to hindrances and disincentives inherent in state and federal policies, there are many other reasons for local government reluctance to adopt strict land-use policies. The most important are a lack of local political will to manage land use, deficiencies in management capacity, and regional fragmentation.

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him- or herself at the expense of the other party. Moral hazard exists in the case of insurance when an insured person has no incentive to avoid the a risk and, in fact, may take action to bring it on in order to collect a financial payoff. It also affects government programs that provide benefits (such as an enhanced level of protection from a hazard such as a flood), thereby relieving the people who benefit from the protection from having to take responsibility for mitigation.

Crisis of Commitment

Few local governments are willing to reduce natural hazards by managing development. It is not so much that they oppose land-use measures (although some do), but rather that, like individuals, they tend to view natural hazards as a minor problem that can take a back seat to more pressing local concerns such as unemployment, crime, housing, and education. Also, the costs of mitigation are immediate while the benefits are uncertain, do not occur during the tenure of current elected officials, and are not visible (like roads or a new library). In addition, property rights lobbies are growing stronger. All of these factors contribute to a lack of political leadership for limiting land use in hazardous areas.

Shortfalls in Capacity

The science of identifying hazards and designing to reduce their adverse impacts has far outrun the ability of local governments to put this new knowledge into practice. Hazard-zone mapping is enormously expensive. Few planning programs provide detailed instruction in hazard mitigation. Many enforcement personnel have insufficient knowledge or support to enforce hazards-related code provisions effectively. Disagreement among state and local policymakers, lack of political power to influence development and environmental interests, and few perceived alternatives all contribute to a lack of capacity on the part of local governments.

Failure to Act Regionally

Yet another problem stems from the fact that hazards do not respect political boundaries and vice versa. In some cases, land-use management programs for hazard mitigation cannot be effective without cooperative intergovernmental coordination, which is difficult to achieve. Such fragmentation also tends to work against considering the cumulative effects of land-use changes.

Conclusion

Promoting appropriate land use has the great potential of not only keeping people and property out of harm's way but also of providing more affordable housing and living conditions, protecting important environmental resources and amenities, and reducing the long-term costs of growth and development, among others. Comprehensive, locally based, land-use management can go a long way toward building sustainable communities.

BUILDING CODES AND STANDARDS

The quality of buildings and other structures plays a direct role in determining lives lost, injuries, and the financial costs of disasters. So disaster-resistant construction is an essential component of local resiliency to disasters. Sustainable hazards mitigation requires that engineered solutions be used wisely and in balance with other approaches to enhance resiliency, environmental quality, economic vitality, intra- and intergenerational equity, and quality of life. The use of building codes can strengthen the nation's constructed environment.

Codes and Standards

The regulation of building construction in the United States is accomplished through building codes. A building code is a collection of laws, regulations, ordinances, or other statutory requirements adopted by a government legislative authority having to do with the physical structure of buildings. The purpose of a building code is to establish the minimum acceptable requirements necessary for preserving the public health, safety, and welfare as well as the protection of property in the built environment. These minimum requirements are based on natural scientific laws, on properties of materials, and on the inherent hazards of climate, geology, and use of a structure.

The primary application of a building code is to regulate new or proposed construction. It has little application to existing buildings unless they are undergoing reconstruction, rehabilitation, or alteration or if the occupancy category is being changed. The term "building code" is frequently used to refer to a set of code books that are coordinated with each other to address specific technical applications. This set of codes generally consists of four documents: a building code, a plumbing code, a mechanical code, and an electrical code. This division is more for convenience than for specific technical or legal reasons.

A standard is a prescribed set of rules, conditions, or requirements with definition of terms; classification of components; delineation of procedures; specification of dimensions, materials, performance, design, or

This home in the Pacific Palisades section of Los Angeles was destroyed in the 1994 Northridge earthquake. Photograph courtesy of AP/Wide World Photos.

operations; description of fit or measurement of size; measurement of quality and quantity in describing materials, products, and systems; and services or practices. There are hundreds of standards in the United States addressing virtually every construction applications, from design practices and test methods to material specification. The building code coordinates this massive quantity of information into an orderly, intelligible, responsive system to safeguard health, safety, general welfare, and property.

There are three basic classifications of standards used in building codes. They are engineering practice standards, materials standards, and test standards. Engineering practice standards define methods of design, fabrication, or construction and specify accepted design procedures, engineering formulas and calculation methods, and good practice. Materials standards are specifications establishing quality requirements and physical properties of materials or manufactured products. Test standards include structural unit and system tests, durability tests, and fire tests. When a particular property of a material, product, or system is required by the building code, the code will specify the standard to which the product is to comply or be tested. It will also state the criteria for determining code compliance.

Model Building Codes

There are three model code organizations active in the United States today. The first, Building Officials and Code Administrators International, Inc. (BOCA), was created in 1915, and represents the eastern and midwestern portions of the United States. The second is the International Conference of Building Officials (ICBO), which produces codes for the West and Midwest. The third, the Southern Building Code Congress International, Inc. (SBCCI), represents the South and Southeast. BOCA publishes the National Building Code, ICBO writes the Uniform Building Code, and the Standard Building Code is produced by SBCCI. Each of these organizations is a nonprofit public benefit service corporation owned and governed by its voting members, which are units of city, county, and state governments as well as the federal government. Each organization develops model codes, provides training in all aspects of codes and code enforcement, and conducts other activities that benefit its members.

In 1994 the International Code Council (ICC) was established to develop a single set of comprehensive and coordinated construction codes. The ICC Board of Directors consists of three representatives from each of the model code organizations. The new codes are referred to as International Codes and are being developed using criteria based on the three existing model codes. A model code has no legal standing until it is adopted as law by a state or local jurisdiction. All owners of property within that jurisdiction are then required to comply with the enacted building code for improvements to their property. The model codes are used as references by design professionals even where the codes have not been adopted in a specific area.

Local and State Codes

Local and state codes vary considerably in degree and procedures. Practically all are based on one of the model codes. At the time of the first assessment (White and Haas, 1975) two decades ago, very few states had state building codes; codes were locally enacted. Since then about half of the states have retracted this delegation of power to the local government and have enacted a state code. The state building code preempts the local government's authority to enact a local code with the same scope and application. The state legislatures have generally taken this action for two reasons: to provide equal protection to all citizens throughout the state and to develop statewide uniformity for commerce purposes.

Local governments have traditionally enacted comprehensive building codes that regulate all construction. The current trend is for states to increase the application of their statewide building codes by replacing the laws that had limited applications. Additionally, state and local governments are relying less on their own custom-drafted building codes and are adopting model building codes, thereby diminishing complexity.

State codes vary from those that merely adopt a particular edition of a model code with administration left to local jurisdictions to those that start with a model code and revise and administer through a separate state-established code body. Many states adopt and administer a separate code only for state-funded buildings, while others may require a special code for certain occupancies, such as schools and assembly buildings.

Local codes are also diverse. Most local amendments are limited to administrative provisions, which are subject to change to meet other local regulations regarding implementation or ordinances.

Enforcement

Even with a statewide code, the administration and enforcement of all building codes rests with the local governments, with varying degrees of state oversight. The local government is responsible for creating the organizational structure for the code enforcement process, designating the person or persons responsible for enforcement, and providing the necessary resources. The local enforcement entity, directed by the code enforcement official, can come in any size or shape. It could consist simply of a one-person department that reports directly to political leaders, or it could be a larger organization that has specialists in all engineering disciplines and operates as a major city or county department. The size and shape of each organization are determined by the amount and nature of construction activity, the relative importance of code enforcement in the priorities of the jurisdiction, and the resources—especially financial—that are available to support the activity.

A building permit process is established for the review, inspection, and approval of proposed activities to secure compliance with the building code. A certificate of occupancy is issued when all inspections have been performed, any deficiencies corrected, and the construction work completed. Any code is only as good as the enforcement that goes along with it. For example, south Florida was thought by most people to have the most rigorous building code in the country, although even it had some deficiencies. However, Hurricane Andrew proved that a rigorous code is ineffective if it is not properly enforced (see Chapter 4).

A survey of building department administrators from jurisdictions of all sizes in the southeastern United States was performed in 1995. Its goal was to assess the perceptions of building code professionals regarding the adequacy of resources at their disposal to administer and enforce codes in their jurisdictions. About half reported that their departments were not adequately staffed to perform all necessary inspections or handle all plan review responsibilities (see Insurance Research Council and Insurance Institute for Property Loss Reduction, 1995).

In an effort to obtain better code enforcement, the Insurance Institute for Property Loss Reduction (now the Institute for Business and Home Safety) instituted the Building Code Effectiveness Grading Schedule. Eventually, every building department in the United States will be evaluated and assigned a rating, which can affect the personal line insurance rates of the community (analogous to the one communities already use for fire protection). It is anticipated that this activity will go a long way toward improving and maintaining rigorous building code enforcement.

Currently, however, there are signficant reasons why building codes may fall short of their loss reduction potential. For example, building codes are for life safety and do not provide for property protection or functionality after a disaster; many local jurisdictions do not have a building official or department; many states allow local jurisdictions to petition waivers from the state-required building code; and state-mandated codes are often reserved only for certain types of buildings and not for most commercial or residential structures.

INSURANCE

Most property owners rely on private insurance to protect themselves against financial losses from ordinary natural disasters such as fires and windstorms. Insurers generally are able to pay for these common losses from the annual premiums collected, supplemented by investment income and reinsurance recoveries. However, most property owners do not currently buy coverage against special perils, notably earthquakes, hurricanes, and floods.

Insurance is now available for some but not all natural disaster agents. It varies from state to state and among carriers. Insurance coverage is nearly universally available for wildfires, winter storms, volcanoes, tornadoes, lightning, and hail. These perils are covered under most standard property insurance contracts. Generally speaking, these events are sufficiently random and widespread to permit the private insurance mechanism to operate effectively.

Landslides are normally not considered an insurable peril by private insurers. They are covered by insurance programs only if the damage is caused by an insured earthquake or flood damage covered under the National Flood Insurance Program (NFIP). Hurricane wind damage is included as part of the basic wind coverage in most property insurance policies. Flood damage from hurricanes is not included but can be purchased separately under the NFIP.

Insurance coverage for damage from earthquakes is not automatically included in homeowners' insurance policies, but it can be purchased as a rider for an additional premium. Earthquake coverage is often included on commercial policies for structures in hazard-prone areas, and it can also be purchased separately. Protection against loss by fires that might follow an earthquake is included in the basic fire peril coverage in all property insurance contracts; business interruption from an earthquake is covered by a separate policy. Until the 1980s fewer than 10 percent of property owners in California had purchased earthquake insurance. Even in areas of relatively high earthquake loss probability, only between 30 percent and 40 percent of property owners purchase the coverage today. Recent earthquakes coupled with a legislative requirement that insurers offer earthquake coverage on a biennial basis have increased the number of California property owners who purchase earthquake insurance.

Insurance companies have viewed flood risk as uninsurable because of problems of both adverse selection and highly correlated risks. In 1968 Congress enacted the NFIP as a means of offering coverage nationwide through the cooperation of the federal government and the private insurance industry. Under this program the federal government conducts the hydrological studies needed to identify areas vulnerable to floods and to define the nature and extent of the hazard. State and local governments are responsible for adopting and enforcing minimum standards for floodplain zoning and construction. Private insurers sell and service the federally underwritten insurance policies, subject to federal standards.

The insurance component of the NFIP is provided at lower rates (subsidized by the premiums paid by other policyholders) for older structures that existed in flood hazard areas before the program began. The number of properties qualifying for subsidized rates has declined over time, while the rates charged have gradually increased to make the program as a whole self-supporting in years with average flood losses. The NFIP borrows from the U.S. Treasury in years when catastrophic losses exceed the amount accumulated in the insurance fund.

Who Should Pay for Disaster Losses?

To address the appropriate role of insurance in sustainable hazards mitigation, the following question needs to be posed: Who should pay for disaster losses? A society that believes that every citizen should share in the losses of disaster victims may find that taxation is the best way to provide the revenue to cover these costs. If, on the other hand, society believes that individuals are responsible for bearing their own burdens, some form of insurance with risk-based rates may be appropriate.

This brings up the question of whether certain individuals or groups should get special treatment at the expense of others. If so, the treatment should be such that situations will not be created that have long-term negative consequences. For example, if uninsured disaster victims are guaranteed grants and low-interest loans that enable them to continue to locate their properties in hazard-prone areas and more people continue to move into the hazardous areas, taxpayers will be subject to increasingly larger expenditures for bailing out more victims in the future. What may be viewed as equitable immediately after a disaster will be seen as inefficient from a long-term sustainability perspective.

If certain victims' disaster costs are to be subsidized by others, private risk-based insurance cannot be counted on to cover damage from these events over a long period, although it can be prevailed upon for a limited time. In the long run such socially motivated subsidies can only be successfully achieved and maintained by some form of government insurance. Historically, attempts to require private businesses to overcharge some groups in order to subsidize others have broken down in a competitive marketplace, despite more and more elaborate enforcement procedures. There is an important difference in the underlying principles of private insurance, where premiums are based on risk and a system in which taxpayers are expected to absorb disaster costs for that segment of the population deemed to require special consideration.

The Demand for Disaster Insurance

Many residents of floodplains and earthquake fault zones choose not to insure their homes and businesses against flood and earthquake damage, even though about 95 percent of them buy insurance for fires, wind storms, and other common perils (see Insurance Research Council, 1996). Only about 20 percent of the homes exposed to flooding are insured against floods, and fewer than that are insured against earthquakes countrywide. However, the demand for earthquake coverage is rising, especially in California. Flood and earthquake coverage of business property also is less than 50 percent (Insurance Research Council, 1991). The result is that millions of property owners in high-risk areas can be expected to turn to federal disaster relief programs in the event of catastrophic floods and earthquakes, placing a heavy burden on taxpayers.

The question raised by such facts is: What factors affect the decision to purchase, or not purchase, disaster insurance? Despite the rational and even highly mathematical calculations of human behavior by economic theorists, the plain fact is that few individuals behave according to economic theory. People do not rationally weigh the costs and benefits of various strategies and then select the one that minimizes costs and maximizes benefits (see Chapter 5).

Researchers who have studied the low demand for flood and earthquake insurance suggest several reasons why many people do not buy these optional coverages. In general, they are much the same as the influences on adoption and implementation of mitigation measures discussed in Chapter 5. In short, people think the premium is too great an expense for an uncertain payoff possibly far in the future; they think that it can't happen to them; they think that federal assistance will make them whole if a disaster does occur; they don't know that appropriate coverage is available (or, in the case of a floodplain property securing a federally backed mortgage, that it is required); or they do not know about the hazard or cannot accurately assess their exposure to it.

The availability of federal disaster assistance is often cited as a reason why floodplain residents do not purchase flood insurance. The prevailing public impression is that federal disaster assistance is generally equivalent to the financial protection provided by hazard insurance. This is simply not true. Except in the case of special initiatives, such as the buyout program after the 1993 Midwest flooding, the primary federal assistance provided to property owners after a disaster is low-interest loans from the Small Business Administration (SBA). Disaster victims who are deemed unable to repay an SBA loan can receive an Individual and Family Grant from the Federal Emergency Management Agency (FEMA). However, each grant is limited to $12,900, and most are much smaller (the average awarded by FEMA in recent disasters is $3,000). Furthermore, they are intended only to meet reasonable needs and necessary expenses, not to make the victim "whole" again. However, despite the fact that by any standard insurance protection is preferable to either a loan or a grant, the public misperception persists and has proved difficult to correct.

Government policy can have significant implications for mandates on the purchase of disaster insurance. One the one hand, such mandates can help combat adverse selection and expand the pool of properties that are insured. This contributes to risk diversification and the capacity of the system to accommodate large catastrophic events. On the other hand, coverage mandates can significantly increase political pressure on insurers and regulators to make coverage available at suppressed prices, and cause regulatory interference with market forces. It may be preferable to encourage the purchase of insurance, short of mandates, and use voluntary mechanisms to ensure the maximum availability and purchase of coverage at the lowest possible price. Of course, this could require the government to be less generous in providing postdisaster aid, which would be a difficult political task indeed.

The Supply of Disaster Insurance

The insurance industry is encountering serious problems in providing insurance for properties located in areas subject to catastrophic losses, particularly those exposed to hurricanes and earthquakes. The problems fundamentally arise from the fact that many insurers now realize they do not have the resources to pay for a so-called worst-case event in those high-risk areas. This is because low-frequency but costly events do not provide a statistical base adequate for sufficiently accurate projections. This is further complicated by the difficulty of aggregating adequate capital over a number of low-loss years in highly competitive financial markets. In addition, insurers face challenges in setting rates based on risk because of the pressures inherent in the current insurance regulatory system.

The realization that resources may not be available to cover claims in a catastrophic event has come only recently in the case of hurricanes, which have been routinely covered by residential and commercial insurance policies for many years. Before 1988 the insurance industry had never experienced a loss greater than $1 billion from a single event. Since that time there have been 15 disasters exceeding $1 billion in insured losses. The pivotal wake-up call was provided by Hurricane Andrew, which generated $15.5 billion in insured losses even though it bypassed the most heavily developed parts of the Miami metropolitan area. Natural disasters costing $50 billion to $100 billion in insured losses are now possible and even likely. Losses of these magnitudes could create unmanageable problems for property owners, mortgage lenders, the insurance industry, and the affected communities.

Insurers confronted by catastrophic loss situations have tried to deal with them by diversifying their book of business to avoid overconcentration in a given state or region, by purchasing reinsurance to spread the risk more broadly, and by charging higher premiums in high-risk areas to cover catastrophic losses. In Florida and California, two of the highest-risk areas, emergency regulations and other laws have hampered insurers' pursuit of those solutions. Some companies have concluded that the resulting risk of insolvency is unacceptable and have attempted to withdraw entirely from those states. Others have stopped writing any new business there until their excessive risk exposures can be reduced.

Insurers also are concerned about questions of equity when faced with the likelihood that catastrophic losses arising from particular states or areas within states will drain off dollars collected to pay losses in other regions and other lines of insurance. For example, the Northridge earthquake produced insured losses of more than $12.5 billion. But only $1 billion in premiums were collected specifically for earthquake shake damage in California in 1994. The Northridge earthquake clearly was subsidized by premiums collected for other purposes and by insurance policies written in other states.

State insurance laws require that premiums not be excessive, inadequate, or unfairly discriminatory. Unlike government welfare plans, private insurance does not deliberately transfer wealth from one state to another or from one class of policyholders to another. This may happen in the short run, particularly when large catastrophes occur, but over time each group and geographical area is supposed to pay its own way.

Many of the political arrangements created recently at the state level run counter to this principle. The most common mechanism is a state-mandated pool, which serves as a market of last resort for property owners when coverage is not readily available from private insurers. Since the pools typically do not charge a premium high enough to cover the catastrophic loss potential of the properties involved, they subsidize the people living in high-hazard areas and impose the excess costs on people residing elsewhere. Moreover, these state pools do not eliminate the problem of catastrophic losses. Private insurers in those states remain liable, on a market share basis, for the net losses generated by the state pools. Thus, any increase in voluntary business carries with it an increase in the insurer's share of the adverse results of the pool. This creates a disincentive for existing insurers to remain in those states or for new companies to establish operations there.

Insurance Regulation

Regulation influences the supply of disaster insurance by controlling insurers' entry to and exit from insurance markets, capitalization, investments, diversification of risk, prices, products, underwriting selection, and trade practices. In theory the job of state regulators is to protect the public from fraud and imprudent practices that threaten insurance companies' solvency and to ensure fair market practices. However, public policy is not forged in a political vacuum, and regulation increasingly has been influenced by voters' perceptions and preferences on how the cost of risk should be shared among different groups. In the process, insurers have largely lost both the freedom to choose the exposures they are willing to insure and the freedom to charge premiums based strictly on a structure's loss potential.

Regulators, too, are faced with a difficult challenge—that of assuring an adequate supply of "affordable" insurance coverage at a time when many insurers are seeking to decrease their disaster exposure and increase their prices for the catastrophe component of that risk. Resolution of this dilemma could have substantial implications for the economies of many disaster-prone areas and their residents.

Mitigation and Insurance

Insurance itself is not considered a mitigation measure because it redistributes rather than reduces losses, but a carefully designed insurance program can encourage the adoption of loss reduction measures by putting a price tag on the risk and creating financial incentives through rate discounts, lower deductibles, and higher coverage limits. There are no easy explanations and no easy solutions to the problem of mitigating and insuring against natural hazards. There is, however, an increasing recognition by those in the insurance sector, the model code organizations, and government that a program must be developed that will address these issues. There are four principal means by which the insurance industry can facilitate mitigation.

1. *Education and information*. A major role for the insurance industry is to engage in educational programs designed to enlighten individual property owners about the risks they face and the mitigation actions they can take to reduce their chances of loss. An informed property owner is more likely to engage in risk reduction and to purchase insurance (see Mileti and Fitzpatrick, 1993).

2. *Participation in the model code process*. The insurance industry must become an active participant in the code development process (as it did before the 1980s). Through this process the industry can make its case for better codes to reduce property losses from natural hazards. The insurance industry has as much at stake in the outcome of these processes as do the homebuilder associations, real estate interests, materials suppliers, and local code officials. After model codes are improved, the insurance industry can actively encourage communities to adopt and enforce them.

One of the insurance industry's most significant concerns is that building codes historically have been designed for life safety and contain few if any provisions for reducing damage to property. This view persists today among model code groups and local building officials, the groups most involved in writing the codes and enforcing them.

3. *Offering financial incentives.* The most frequently suggested financial incentives are insurance premium reductions, changes in the amount of the deductible, and changes in coinsurance schedules, which reflect the changes in risk resulting from the implementation of a mitigation program. In the case of premium reductions, individuals would compare the reduction in premium offered with the estimated cost of mitigation action and decide whether the mitigation measure is beneficial based on a perception of the risk. It should be noted that, before a premium can be reduced (as an incentive), it must develop sufficient funds to pay for losses. In addition, any premium incentive must be approved by state regulators (except for the NFIP, which as a federal program is not subject to state regulation). Deductibles and coinsurance involve risk sharing and are designed to encourage property owners to protect against small losses, which also benefits insurance companies by reducing the expense of dealing with small claims.

The high front-end cost of mitigation versus a premium reduction spread over many years may weaken the financial incentive. It could, however, be bolstered with noninsurance incentives that would yield benefits to the property owner who holds a policy in the shorter term (e.g., a waiver of property taxes that would be derived from the increase in the property's value as a result of the retrofit, a waiver of sales tax for materials used in the retrofit, or a waiver for building permit fees.) Innovative financing programs could help, like long-term loans tied to mortgages or awarding a mitigation seal of approval to raise the price of a house at resale.

4. *Limiting the availability of insurance.* Property owners would be most likely to implement mitigation measures if insurance were not available until after the property had been built or retrofitted to an acceptable standard. Given sufficient market penetration, the application of market forces that make the availability of financing and insurance for buildings dependent on their meeting certain high mitigation standards should help motivate builders to build to a higher standard and owners to retrofit existing properties.

Summary

Dealing with natural disasters of the magnitude now predicted, and to nest insurance within sustainable hazards mitigation, will require new policies to encourage or require property owners to take cost-effective mitigation efforts and to provide compensation to cover the losses. Private insurance can pursue both of these sustainability strategies, but the problems may be too large for the insurance industry alone to handle. Public programs such as disaster relief also have a role to play, but their cost is becoming increasingly burdensome to taxpayers and they offer no incentive to undertake mitigation. There is an opportunity to utilize insurance as an important part of a hazards management program that would encourage and enforce cost-effective loss reduction measures. The limited use of such measures on existing structures in the United States indicates that new approaches must be developed by key stakeholders such as the insurance industry, financial institutions, state regulators and insurance commissioners, the building industry, inspectors, and real estate developers for reducing losses from these catastrophic events.

The new strategy should include improved estimates of risk, certifications of damage resistance, heightened enforcement, a policy decision about whether and how to subsidize mitigation and/or disaster losses for low-income households or others, and additional ways to protect the insurance industry against insolvency. Progress will require the direct involvement of government at all levels to link insurance and mitigation. Technical assistance, especially in risk assessment and testing and evaluating new mitigation methods, will provide the insurance industry with improved understanding of the risks.

PREDICTION, FORECAST, AND WARNING

The United States has no comprehensive national warning strategy that covers all hazards in all places. Instead, public warning practices are decentralized across different governments and the private sector. Uneven preparedness to issue warnings exists across local communities; hence, people are unevenly protected from the surprise onset of natural disasters. Without changes in this situation, inequities will grow larger, and the gains made in saving lives over the past decades may well be reversed.

Warning systems detect impending disaster, give that information to people at risk, and enable those in danger to make decisions and take action. This definition is simple, but warning systems are complex, since they link many specialties and organizations—science (government and private), engineering, technology, government, news media, and the public. The most effective warning systems integrate the subsystems of detection of extreme events, management of hazard information, and public response and also maintain relationships between them through preparedness.

Hazard-Specific Knowledge

Since the first assessment (White and Haas, 1975) was completed, there have been significant improvements in forecasts and warnings for some hazards but only marginal improvements for others. Forecasts for flood, hurricanes, and volcanic eruptions have improved most significantly, and public dissemination of warnings has improved the most for hurricanes. A 100 percent reliable warning system does not exist for any hazard.

Flood

Flood forecast and prediction capabilities evolved slowly during the 1970s and 1980s; more recent advances could have a major impact on forecasting (e.g., systems under development at the National Weather Service [NWS] include the NEXRAD Doppler radar, the Advanced Weather Interactive Processing System, and the Automated Surface Observing System). Floods are forecast by hydrological models that estimate flood conditions based on predicted or measured parameters, through physical detection systems, or a combination of the two approaches. Flash floods remain difficult to predict. Public flood warning dissemination and integration capabilities have improved only marginally.

The NWS is the only federal entity with a mandate to issue flood warnings, but other groups also are involved—for example, local floodplain managers, the U.S. Army Corps of Engineers, the U.S. Bureau of Reclamation, and private forecasters. Locally based detection systems also exist in many communities.

Tornado

There have been significant improvements in warnings for tornadoes over the past two decades. In 1978 warnings were issued for 22 percent of tornadoes; the average lead time was three minutes. In 1995 the percentage had risen to 60 and the lead time to almost nine minutes. The nation is moving from "detected" warnings to an era of "predictive" tornado warnings. Tornado prediction has improved over the past 20

years because of geosynchronous satellites (GOES), improved use of radar, better training for forecasters, and improved local storm spotter networks and awareness campaigns. Models of how tornadoes form have matured from simple ones to those using parent circulation (mesocyclone) at midlevels in thunderstorms.

Dissemination of tornado warnings to the public and emergency managers is significantly different now compared to two decades ago. One change has been the growth of the private-sector weather information industry. Another advancement has been the growing ability of the news media to quickly get warnings to their audiences. Finally, meteorological support companies now provide many services that allow meteorologists to create their own forecasts and on-air displays.

Hurricane

The National Hurricane Center (NHC) in Miami, part of the NWS, is responsible for predicting hurricane behavior and issuing warnings. Other entities also make hurricane forecasts, but only NHC forecasts are

A tornado tore a hole in downtown Clarkesville, Tennessee on Friday, January 22, 1999, destroying historic buildings and knocking out power in much of the city, but causing only minor injuries. It ripped the roof off the courthouse and knocked down most of a church. Photograph courtesy of AP/ Wide World Photos.

disseminated through the NWS's centralized computer system. Private meteorological firms provide operational hurricane forecasts to private industry clients and state and local governments.

Predicting hurricane behavior has three components: (1) collecting accurate data about the hurricane itself—location, wind and pressure profiles, speed and direction—and about the surrounding atmosphere; (2) anticipating changes in the associated meteorological environment; and (3) understanding why hurricanes behave the way the do. Hurricane data are provided by satellites, reconnaissance aircraft, buoys, ships, and coastal radar and are crucial for identifying the hazard, detecting trends, and establishing initial conditions required by predictive models. Visible and infrared satellites provide useful indications of a hurricane's center location, central pressure, and wind velocity. However, they are not accurate enough for some predictive models. Hurricane forecasts are most accurate in the Gulf of Mexico because there is a denser network of data about the atmosphere there (Sheets, 1990).

Hurricanes are part of large air masses. One aspect of forecast difficulty is anticipating the changes in those masses and determining how

TABLE 6.1 Maximum Hurricane Strike Probabilities for Forecast Time Frames

72 hours	10%
48 hours	13-18%
36 hours	20-25%
24 hours	35-50%
12 hours	60-80%

SOURCE: National Hurricane Center and Emergency Management Institute, 1995.

they influence a hurricane. Much effort is expended on discovering those influences and incorporating them into predictive models. Models often disagree, so forecasters consider the output from all models and then make forecasts. Official forecasts are three hours "old" when released.

The NHC generates a variety of forecast-related products. Public advisories are intended primarily for use by the news media. They give current hurricane conditions and indicate the general direction of a hurricane, if it is expected to strengthen, the peak storm surge expected, and the amount of predicted rainfall. The possibility of tornadoes may be noted, along with appropriate actions to be taken by the public. Public advisories may also include tropical storm watches and warnings.

A hurricane watch is issued for 300 or more miles of coastline when NHC forecasters believe a hurricane can strike land within 36 hours. When forecasters believe a hurricane can strike land within 24 hours, the NHC issues a hurricane warning, also for a broad stretch of shoreline. A tropical cyclone forecast/advisory contains specific forecasts regarding where, how strong, and how large a hurricane will be in 12, 24, 36, 48, and 72 hours, in addition to comparable current information about the hurricane. A strike probability forecast indicates the probability that the center of a hurricane will pass within 65 miles of a list of locations in certain time frames. As a hurricane approaches shore, forecasts become better. Table 6.1 indicates the largest strike probability values any place will have at certain periods from landfall.

Position (or location) forecasts are most accurate for time frames closest to the current time. Over the past 25 years, 24-hour position forecasts have been improving at an average rate of 1.1 percent per year (McAdie, 1996). Over the same period, 48- and 72-hour forecasts improved 1.5 percent and 1.2 percent, respectively.

Historically 90 percent of the people who have died in hurricanes have drowned in storm surges. The NHC uses a computer program named Sea, Lake, and Overland Surges from Hurricanes (SLOSH) to predict the height and areal extent of storm surges. Inundation scenarios are created and put into a SLOSH atlas, which depicts the maximum heights throughout a community for each storm category.

Evacuation planners anticipate the coastal area that will need to be evacuated because of the storm surge, how long the evacuation will take, and what accommodations must be provided to evacuees. Studies for such plans are funded by FEMA, the U.S. Army Corps of Engineers, NHC, and sometimes state emergency management agencies.

Drought

Droughts differ from other natural hazards in four ways: (1) there is no universally accepted definition of drought; (2) drought onset and recovery are usually slow; (3) droughts can cover a much larger area and last many times longer than most natural hazards; and (4) droughts are part of the natural variability of virtually all climatic regimes, rendering the entire United States at risk (Wilhite, 1993). These differences have prevented many state and local governments from establishing drought mitigation or contingency plans, including early warning and detection systems.

A reliable long-term forecasting model for droughts does not now exist. Scientists are striving to predict droughts by concentrating on teleconnections between large-scale atmospheric/oceanic anomalies and drought. In order for a meteorological drought to occur, usual precipitation patterns must be disrupted. Forecasting meteorological conditions is only part of predicting a drought. The severity of drought also depends on the moisture content of the soil and the general health of vegetation.

Remotely sensed data can be used to determine both plant health and soil moisture content. The National Oceanic and Atmospheric Administration's (NOAA's) advanced very high resolution radiometer data have been used to produce an index of vegetation conditions, which has brought particularly good results in drought detection and can contribute to early warnings. For short-term forecasts the NWS already provides 3- to 5-day and 6- to 10-day precipitation forecasts. In addition, 30- and 90-day outlooks are issued.

Improvements in drought prediction and forecasting are developing on three fronts. First, scientists are gaining a better understanding of the interactions and feedback mechanisms between physical systems and the causes of drought. Second, there have been continued technological advances in meteorological/climatological instrumentation. As the accuracy, dependability, and durability of these instruments improve, so will the quality of the data gathered. The combination of more accurate and consistent data and better models should result in more reliable predictions and forecasts. Third, there is a more widespread recognition of the importance of integrating physical and social parameters at the community level. Currently, little is known about how drought forecast information would be used by decisionmakers.

A national drought policy and plan was initiated in 1987. This plan was designed to help state governments prepare for droughts. Ten essential but flexible steps were delineated (Wilhite, 1993). An early warning system was one of the mitigation measures suggested, but it has yet to be established.

Snow Avalanche

The first regional snow avalanche forecast center in North America was founded in 1962. Today there are nine such centers—two in Canada and seven in the United States. They are responsible for monitoring and forecasting avalanche danger in backcountry or highway corridor areas ranging in size from 1,000 to 100,000 square kilometers.

A recent survey of the centers (Williams, 1996) determined that they use the latest technologies to gather and receive data and to disseminate forecasts—automated remote data stations, manned observation sites, stability tests, and reception and dissemination via modem, fax, mail, and the Internet. However, few technological aids are used in data analysis and decisionmaking. Rather, all of the centers rely on conventional avalanche forecasting—using measurements, observations, experience, intuition, and knowledge of prevailing local terrain, weather, and snowpack conditions.

The state of the art in snow avalanche forecasting is dependent on the amount and type of research being conducted. In the United States very little research is being done because of a lack of federal and state funding. Consequently, U.S. forecast centers rely on research findings and technology imported from other nations. Among the technological advances, products, systems, and methods available for snow avalanche forecasting are remote automated weather data systems; improved NWS numerical forecast models; nearest-neighbor models; expert systems; avalanche hazard indexes for highways; stability tests such as shovel shear, rutschblock, compression, and stuffblock; geographic information systems (GISs); e-mail; and the Internet.

Technological advances have greatly improved the methods by which centers gather and receive data and disseminate their forecasts, but new technology is scarcely used for analysis and decisionmaking. Centers rely almost totally on conventional methods of avalanche forecasting based on experience, intuition, and local knowledge for many reasons: conventional forecasting is a proven method; regional forecast centers must analyze large amounts of weather, snowpack, and avalanche data gathered over large tracts of mountainous terrain, which compounds the problem of trying to use numerical techniques to aid analysis; the decisionmaking process in avalanche forecasting does not lend itself to modeling; and there is no budget for research and development of new technology to produce a useable and sophisticated computer aid for conventional forecasting.

Wildfire

Forecasting fire behavior depends on predicting the interaction of topography, fuels, and weather, especially to predict quickly how changing weather will affect a fire. Warning systems for the prediction of wildfire behavior include fire danger rating systems and fire behavior modeling systems. Rating systems usually attempt to predict the probability of ignitions. The system will then try to predict the potential fire behavior for a relatively large area. Fire management organizations use this information to plan readiness levels of fire-fighting staff and restrictions in human uses of wildlands and equipment.

At present all agencies in the United States use the National Fire Danger Rating System (NFDRS). The system is also used by local fire agencies that oversee the urban/wildland interface. Recent improvements in the NFDRS include the use of remote automatic weather stations. These stations can be located anywhere and will transmit the data necessary to calculate fire danger as well as give local weather for other planning such as prescribed burning. Every three hours a station is triggered by the GOES satellite to transmit data to it. The satellite then transmits the data for calculation.

Current shortcomings in the system stem from three sources. The first is the limited ability to understand the basics of fire dynamics in complex fuel, topography, and weather systems. A second source is the broad nature of fuel models and the large areas over which predictions must be made. By far the greatest source of failure, however, is the inability to predict weather accurately enough and far enough in advance over the complex terrain that is often involved.

Fire behavior prediction in the United States is presently based on the BEHAVE system (Andrews, 1988), which draws on the fire behavior models originally published in 1972 and improved upon over the past 20 years. The program will provide the rate of spread, fireline intensity, heat release per unit area, and flame length. The operator can also ask for the distance that the fire will spread in given time periods. Recent work has led to the real-time prediction of a moving fire and given personnel better information on how and where to fight a fire and make better evacuation decisions.

Earthquakes

Programs directed at predicting earthquakes have had mixed success. Through statistical analysis of earthquakes worldwide, the frequency of different-magnitude quakes across the globe can be estimated. The monitoring of global seismicity also makes it clear that certain areas are much more prone to quakes than others. For example, 90 percent of the world's earthquakes occur on the boundaries of large tectonic plates. Along a single plate boundary, however, there can be considerable variability in the size and frequency of significant earthquakes. Parts of the San Andreas fault accommodate the relative motion of the North American and Pacific plates without earthquakes through aseismic slip; other sections of the fault have experienced several large or major quakes during recorded history. In general, intraplate earthquake sources and processes are even less well known. Thus, a better understanding of the relationships among plate tectonics, regional stresses, and earthquake sources is needed.

Scientists are making progress in understanding earthquake genesis and growth. Recent observations suggest that conditions favoring the growth of large, potentially destructive earthquakes are fundamentally different from those that lead to smaller, more common events. If so, careful geological and geophysical monitoring might someday detect the conditions that signal imminent earthquake risk (see Ellsworth and Beroza, 1995).

Local geology and topography may also have a role in whether larger, less frequent quakes—or smaller, more frequent ones—are to be expected on a fault. Advanced models of rupture propagation, additional geophysical data, and additional seismological data from newer broadband high-dynamic-range instruments will likely aid in understanding how surficial and subsurface fault characteristics affect rupture and maximum magnitude.

The standard approach to developing a prediction capacity hinges on the earth's providing recognizable signals of impending quakes. Theoretical and laboratory studies indicate that there should be preliminary phases before rupture. Potential earthquake precursors include foreshocks, changes in the groundwater table, other hydrological or hydrothermal phenomena, deformation of the earth's surface, changes in the rock's electrical conductivity or magnetic properties, and changes in seismic wave properties through the area in question. In the past, such phenomena have been observed in the field but not consistently.

Some advances in the detection of earthquake and seismological data, as well as dissemination, have been made. The CUBE (California Institute of Technology-U.S. Geological Survey [USGS] Broadcast of Earthquakes), in southern California, and REDI (Rapid Earthquake Data Integration) in northern California, are programs that provide rapid information, including the magnitude, location, depth, and other data on California earthquakes. Data from the University of California at Berkeley, Caltech, and the USGS seismic networks are automatically processed for earthquake parameters, and the information is distributed by pager, e-mail, and the World Wide Web. Recipients of these earthquake data include public and private agencies in emergency services, utilities, and lifelines.

TriNet is a five-year $20 million project to develop a state-of-the-art digital seismic network in southern California. The TriNet partners include the USGS, the California Division of Mines and Geology, and the California Institute of Technology. The project will result in tangible seismic safety benefits that include accurate and reliable locations and magnitudes of earthquakes and maps of the regional distribution of ground shaking within five minutes of a significant earthquake. TriNet will also develop a pilot earthquake early warning system for southern California.

The first U.S. effort directed at earthquake prediction was located near the central California town of Parkfield, adjacent to the San Andreas fault. The Parkfield prediction experiment was begun in 1985 after analysis of previous earthquake occurrences on a particular fault section indicated that a repeat event would occur near the end of the decade (Bakun and Lindh, 1985).

In November 1988, two USGS scientists submitted to the National

The climactic eruption of Mount St. Helens, May 18, 1980, at about noon. The maximum height of the ash and gas column was about 12 miles. Photograph by Robert M. Krimmel.

Earthquake Prediction Evaluation Council (NEPEC) data indicating that the chances of an earthquake were very high. Within three months both NEPEC and the California Earthquake Prediction Evaluation Council had endorsed the scientists' prediction. Thus, the Parkfield experiment became the first scientifically credible long-term earthquake prediction. The director of the USGS issued a formal public forecast of the quake in April 1985, stating that there was a 90 percent probability of a magnitude 5.5 to magnitude 6.0 earthquake sometime between 1985 and 1993 in the Parkfield area. It also stated that a 10 percent probability existed for a magnitude 7.0 quake. The release of this forecast became a national media event and precipitated a media campaign in central California involving newspapers, radio, and television that lasted years. In 1988 the California Governor's Office of Emergency Services published a detailed brochure and mailed it to 122,000 households at risk. It covered information about the earthquake hazard, the prediction, a possible short-term warning, and how to take action. But the expected characteristic earthquake never happened. Further analysis showed that, while the successive repeat of similar but not identical quakes might be expected on individual fault sections, the amount of time between them may be highly variable. Confidence in predictors based on estimates of recurrence intervals has decreased; scientists are more sanguine about the possibility of identifying one or more of the "red flags" described above.

Volcanoes

Volcano hazard forecasting and prediction includes forecasting explosive events and assessing volcanic hazard. In the past 20 years considerable progress has been made in identifying the extent and magnitude of hazards at high-risk volcanoes. But scientists have had mixed success with predicting the timing and magnitude of volcanic eruptions. Predictions have been most successful for volcanoes with frequent eruption cycles and most difficult for large caldera systems with low recurrence intervals. An obstacle to prediction advancement is lack of instrumentation and monitoring on most active volcanos around the world. Although efforts have been made to integrate hazard assessment into emergency planning, there is not much evidence of integrated volcano warning systems in potentially hazardous areas in the United States. A current trend is toward developing planning scenarios based on the information in a volcanic hazard assessment, which could be used to design a warning system.

The monitoring activities associated with prediction fall into the categories of seismic monitoring, seismic tomography, ground deformation monitoring, electromagnetic monitoring, and geochemical monitoring. The greatest progress has been made in recent years in understanding volcanic structure and eruption dynamics. Seismic tomography techniques have led to better understanding of the subsurface structure of volcanoes, and modeling of stress-strain buildup as an eruption precursor has advanced considerably. Some success has been achieved with gas emanations modeling. In contrast, geoelectric monitoring and geomagnetic monitoring have produced inconsistent results.

Tsunamis

Tsunamis are instantaneously generated traveling waves of water. Most tsunamis occur in the Pacific and Indian oceans, but they also occur in almost all large bodies of water. All great oceanwide tsunamis are generated by large subduction-zone earthquakes, but large local waves can be generated by submarine and subaerial landslides, various volcanic processes, and other phenomena. The characteristics of their generation and propagation provide the means for detecting tsunamis and issuing warnings. Because the causative earthquakes are very large and near the coast, they can be recorded around the earth in minutes. It is possible to detect them, locate the epicenter, and calculate the magnitude in about 30 minutes, well before the arrival of tsunami waves from remote sources (it takes from several hours to a day for a wave to reach the opposite coast) but not necessarily before the arrival of a locally generated tsunami.

Improvements in the past 20 years in warning and forecasting technologies for tsunamis have been mainly in communications and procedures. This includes the real-time satellite communication of analog seismic and tide gauge data from stations around the Pacific to warning centers. Use by the Japanese and the National Earthquake Information Center of computers that can automatically scale incoming data and compute locations and magnitudes have speeded up the warnings. The recent development of deep-ocean gauges promises to provide rapid data on wave heights from the open ocean, uncontaminated by shoaling phenomena as are gauges in harbor locations. So far these gauges are operated off the Shumagin Gap area in Alaska, the state of Washington coast, and Hawaii. Their more general deployment will result in substantial improvement in the system.

Computer models have been of limited use in predicting runup for inundation mapping, partly because of the lack of good initial data. Models should be useful in reconstructing the source conditions, but again, their success has been limited. Predicting the height of waves from remote sources at specific localities also should be possible with models, but so far it has not been done.

Landslide

Landslide prediction and forecast in the United States has traditionally focused on identification of landslide-prone areas and potential slide locations. Landslide hazard studies are carried out in areas with repeated high economic losses from landslides. Typical studies include regional identification of landslide potential, evaluating the kinds and intensities of landsliding, determining their areal distribution and frequency, and studying landslide processes. To date, such studies have produced deterministic maps of landslide potential. These provide useful information for educating people about the hazard but are not particularly useful for issuing forecasts. Probabilistic landslide maps have not been extensively produced but likely will be in the future. They require the development of an historic frequency of landslide occurrence as well as a better understanding of rainfall intensity duration thresholds.

Progress has been made in predicting and forecasting both conditions that may lead to an alert for increased landslide potential in a region and the triggering of landslides at a specific site. Predicting and forecasting landslides depends on comparing precipitation and snowmelt forecasts and real-time observations to threshold values associated with the triggering of a landslide. Thresholds for rainfall-induced debris flows have been successfully developed for the San Francisco Bay area, and thresholds for snowmelt-induced landsliding and debris flows have been developed for the central Rocky Mountains.

Landslide prediction and forecast systems are also being used in conjunction with both seismic- and volcanic-induced landsliding. Work in southern California focuses on the near-real-time prediction of earthquake-induced landslides by combining measurements of strong ground shaking during an earthquake with GIS-based datasets on topography, geology, engineering strength, seismic intensities, and historic landslides. Work on volcano-related landslides characterizes the strength of volcanic rock, models the effects of destabilizing thermal pressurization, and models volcanic edifice stability.

The Landslide Hazard Program (LHP) of the USGS is a Congressionally authorized program dedicated to the reduction of landslide damage. The USGS also has been delegated the responsibility of providing landslide warnings. Until recently there has not been a mechanism to promote the dissemination of landslide prediction and forecast information to people in hazardous areas. The USGS National Landslide Information Center, in cooperation with the LHP, is developing a communications center for issuing advisories, press statements, and other information about landslides.

Technological Hazards

Technological hazards are products of industrialization that pose a health or safety threat to humans. Typically this includes nuclear materials, chemicals, and hazardous materials, including explosives, oil and gas products, and wastes. They can occur at stationary facilities or during transportation. Warning systems are much more feasible for fixed facilities, but their feasibility varies greatly according to the industry and location in the country. The prediction and forecast of technological hazards involves a complex process that is specific to the technology and/or materials involved. The basic approach is to estimate an accident sequence consisting of an initiating event, a release mode and a quantity and to model the dispersion of the release as it occurs—either visually or with instrumentation.

For this second assessment of hazards, technological hazards were viewed as secondary effects of natural events. Two approaches have been used to further understanding of the conditions under which natural events will lead to releases of hazardous materials. First, case studies and reviews of historical events have been conducted. These have led to fairly detailed inventories of the type of materials released in various events, although it has been argued that improved methods and much more careful study are needed. The second approach has been to model such releases using probabilistic risk assessment methods that typically include accident scenarios involving earthquakes, floods, tornadoes, lightning, storm surge, and high winds.

Emergency response requirements for chemicals and hazardous materials fall under a number of regulatory programs, particularly the Resource Conservation and Recovery Act, the Superfund Amendments and Reauthorization Act Title III, and the Clean Air Act's Risk Management Planning. All require some level of hazard disclosure by the material owner to communities to assist with a local warning system. These programs and their associated planning guides are vague about specific needs for alert and notification requirements. Another federal program is the Chemical Stockpile Emergency Preparedness Program (CSEPP). The CSEPP planning guidance contains detailed design criteria for a state-of-the-art alert/notification system. Warning systems developed at the eight CSEPP sites meet or exceed those for nuclear power plants.

Most communities with chemical or hazardous materials hazards do not have special warning systems. Most of the existing systems were developed primarily by individual private companies and communities as cooperative efforts. Research has shown, however, that in most chemical or hazardous materials accidents the prime responsibility for issuing a warning falls on local emergency response organizations, which are the first to arrive at the scene of a spill. The primary warning problems these organizations face are identifying the hazardous materials involved in an incident, determining the threat presented, and then deciding who to warn and what to tell them. Some communities have plans to guide this activity, but most incidents require ad hoc responses.

The Three Mile Island nuclear accident and the Bhopal, India, chemical accident revealed the need for monitoring and detecting nuclear power plants and many large chemical plants. But not all chemical and hazardous materials handlers have developed the ability to monitor conditions or predict or detect releases. There have been significant improvements over the past 20 years in problem recognition and identification, identifying options for protective action, and improving decisionmaking by development of decision support systems. A variety of dispersion models, decision support tools, integrated models, and emergency management information systems have evolved in various chemical response programs. As such systems develop, fuller integration of technological and natural hazard decision support efforts can be anticipated.

Evacuation has always been the preferred means of protecting the public from an accident. In the past 20 years much work has been done on alternatives to evacuation. Shelter in place—or protecting people where they are, without evacuating them—is accomplished by shielding the public from exposure pathways—vapors, aerosols, and liquid contamination. Shelters may be congregate (for many people) or individualized (a home). Shelters may be existing structures, with or without upgraded protective measures, or facilities specifically designed to protect from toxic chemicals.

Cross-Cutting Knowledge

A great deal of forecast and warning-related knowledge applies to several or all hazards. Much, but not all, of this knowledge resides in the social sciences.

Nation-Wide Approaches

The Civil Defense Warning System (CDWS) and the Emergency Broadcast System (EBS) were developed to warn of enemy attack, accidental missile launch, or radioactive fallout. The CDWS combined national, state, and local resources, but the heart of the system was the National Warning System (NAWAS). Operated by FEMA, it consisted of a series of nationwide, dedicated, 24-hour telephone lines, two national and 10 regional warning centers, primary warning points, state warning points, extension warning points, and duplicate warning points. The NAWAS was supplemented by state and local civil defense warning systems that transmitted warnings to officials and the public. State civil defense offices are usually linked to other state agencies, county sheriffs, and civil defense agencies. Local civil defense officials transmitted warning information to institutions and to the general public, primarily through local television and radio stations. EBS could be activated at the local level for community emergencies. The National Oceanic and Atmospheric Administration has developed Weather Radio to provide warnings of severe weather through commercially available tone-alert radios. Broadcast stations exist around the country, each serving a 40- to 60-mile radius.

In 1994 the Federal Communications Commission announced the creation of the Emergency Alert System (EAS) to replace the EBS. EAS will cover both national and local emergencies and is designed to take advantage of current digital communications technology. All commercial broadcast stations and cable companies are required to participate in the system. Some of the features of the new system will include multiple alerting sources, remote operations, and targeting of specific geographical areas. The EAS and NOAA Weather Radio program are being integrated so that the EAS can activate the tone-alert radios. Except at the local level, EAS is not tied to any other hazard warning systems.

Warning Response

A great deal is known about how and why people (individuals, families, and organizations) respond to warnings. This knowledge has already been summarized (see Drabek, 1986; Lindell and Perry, 1992; Mileti and Sorensen, 1990) and key points are presented below.

Coordination and communication between the different organizations that are part of a warning system are essential to the issuance of timely public warnings. The conditions that facilitate and/or undermine coordination and communication between warning system organizations are well defined. Simply stated, coordination is maximized when organizations know what they and other organizations are supposed to do, know who in the organization is to do it, have designated and understood communication ties to other organizations in the system, and maintain flexibility. Communication problems, owing to both equipment and human failure, are the most significant causes of poor warning dissemination.

A fairly thorough understanding of warning compliance has been developed by social science researchers. The focus of their research has been on whether or not people evacuate when advised to do so. In contrast, little work has been conducted on how people choose protective actions. Nor have individual variations in response to warnings been explained, such as why some people act immediately and others delay (Sorensen, 1991).

Warning response is a process with several stages: (1) hearing the warning, (2) believing the warning is credible, (3) confirming that the threat does exist, (4) personalizing the warning to oneself and confirming that others are heeding it, (5) determining whether protective action is needed, (6) determining whether protection is feasible, and (7) determining what action to take and then taking it (see Lindell and Perry, 1992; Mileti and Sorensen, 1990).

Both general and specific factors that affect public warning response have been identified. These include characteristics of the message sender, the receiver, the message itself, and the social context a person is in when a warning is received (Mileti and Sorensen, 1990). These factors are summarized in Table 6.2.

The chief way that warning response can be affected by emergency planning is in the design of the warning system, including the channel of communication, preevent education, and how the emergency message is worded. Incentives also can be offered to increase response, including information hotlines, transportation assistance, mass care facilities, and security to protect property left behind.

Much progress has been made on measuring and modeling warning dissemination and response (see Sorensen and Mileti, 1989; Lindell and Perry, 1992). The knowledge generated includes data on the time that decisionmakers take to reach a decision to issue a warning, the time it takes to disseminate a warning via different technologies and strategies, the time it takes people to reach a decision to act on a warning, and the

TABLE 6.2 Major Influences on Response to Warnings

Factor	**Direction of Impact on Public Response**	**Empirical Support**
Physical cues	Increases	High
Social cues	Increases	High
Perceived risk	Increases	Moderate
Knowledge of hazard	Increases	High
Experience	Mixed	High
Education	Increases	High
Family plan	Increases	Low
Fatalistic beliefs	Decreases	Low
Resource level	Increases	Moderate
Family united	Increases	High
Family size	Increases	Moderate
Kin relations (number)	Increases	High
Community involvement	Increases	High
Ethnic group member	Decreases	High
Age	Mixed	High
Socioeconomic status	Increases	High
Gender (female)	Increases	Moderate
Having children	Increases	Moderate
Channel: electronic	Mixed	Low
Channel: media	Mixed	Low
Channel: siren	Decreases	Low
Personal contact	Increases	High
Proximity to threat	Increases	Low
Message specificity	Increases	High
Number of channels	Increases	Low
Frequency	Increases	High
Message consistency	Increases	High
Message certainty	Increases	High
Officialness of source	Increases	High
Fear of looting	Decreases	Moderate
Time to impact	Decreases	Moderate
Source familiarity	Increases	High

SOURCE: Mileti and Sorensen, 1990.

time it takes to carry out alternative protective actions such as evacuating or taking shelter. Additionally, many other lessons have been learned from warning research since the first assessment (White and Haas, 1975). Some of the more significant lessons include that officials are often slow to reach a decision about issuing a warning, and slow decisions often prevent an effective public warning; most populations can be notified in about three hours or less without specialized warning systems; warnings are more slowly disseminated at night; new warning technologies, such as telephone ring-down systems, can achieve very rapid warning times; informal notification plays an important role in the warning dissemination process in most emergencies; the time people spend responding to a warning corresponds to an s-shaped (logistic) curve; and, surprisingly, the time required to evacuate a population is unrelated to its size.

Alert and Notification Technology

A public warning is often considered to have an alert component and a notification component. The alerting phase gets people's attention with sound or other sensory stimuli. The notification phase communicates the information. Significant improvements have been made in alert and notification technologies over the past 20 years. Mechanical sirens, which only provided an alert signal, have been augmented with electronic sirens that can also broadcast voices. Electronic signs, some of which can be remotely activated, are now available for use on highways. Special tone-alert radios that can be remotely activated (like NOAA's Weather Radio) can be installed in homes or businesses to provide indoor alerts. Cable overrides have improved the use of television as a warning mechanism. Telecommunication devices for the deaf and strobe lights have improved the ability to communicate with people with certain disabilities. Other advances include telephone ring-down systems, which either use computers to automatically dial sequential banks of telephones or switching equipment that simultaneously dials a large number of phones.

As the communications revolution advances, new warning technologies likely will be developed and commercialized. The EAS SAME technology has increased the efficiency of television and radio for warnings. This technology will eventually enable remote activation of consumer products such as car radios to receive messages being disseminated over commercial stations. Improved tone-alert radios are being developed. The National Aeronautics and Space Administration is developing an alert and notification system that would use satellites to activate individual pagers. Most of these newer technologies have not been systematically investigated in a field setting, so it is not yet known whether they will be more effective alert and notification techniques.

Effectiveness

Much has been learned since the nation's first assessment of national hazards (White and Haas, 1975) about the timing of warning dissemination. The most significant debate on what constitutes a state-of-the-art alert and notification system came in an Atomic Safety Licensing Board (ASLB) proceeding on the Shearon Harris Nuclear Power Plant. In its final ruling the ASLB defined what constitutes "essentially 100 percent notification within 15 minutes in the first 5 miles of the Harris Emergency Planning Zone" (Atomic Safety and Licensing Board, 1986). The ASLB required the utility to establish that over 95 percent of the people within 5 miles of the facility would receive a warning within 15 minutes. In order to exceed the requirement, tone-alert radios were proposed for all households within the 5-mile radius.

Expedient warning remains a thorny problem for natural hazards emergency managers since some fast-moving events can provide no or only a few minutes of warning time. New warning technologies are needed for rapid warning dissemination.

Community Adoption

Little is understood about the adoption of community warning systems in the United States. There is strong anecdotal evidence that the NAWAS is poorly maintained at the local level and in most communities uses outdated control, alert, and testing technology. The new EAS strategy will only partially address problems of community adoption. As currently formulated, it is based on indoor technology and thus can only reach people already tuned in to the media.

Only one study has systematically investigated the adoption of warning systems; it was based on a national sample of communities and focused on chemical releases (Sorensen and Rogers, 1988). It showed that few communities used state-of-the-art communications equipment or warning system technology. The ability of the majority of systems to provide a timely alert and notification was highly questionable. Few communities had well-developed plans and procedures to guide emergency response. Notably lacking were organizational capabilities to make decisions.

Social Issues

The development and use of effective warning systems present several economic, ethical, and cultural issues.

Cost-benefit analysis. Two approaches have been used to estimate the costs and benefits of warning systems. First, average annual costs for warning preparedness are compared to the average number of lives saved by the system. In such analyses the benefits reaped can appear low for disasters that occur infrequently. A second type of analysis focuses on the potential for the infrequent catastrophe. This approach compares the cost of warning preparedness to the benefits of the system when the maximum credible disaster does occur. Most cost-benefit analyses of warning systems use both approaches. The results can vary widely across hazards as well as for the same hazard in different communities. Some decisions about warning system adoption and preparedness do rest on cost-benefit analyses. But often warning systems are developed based on humanitarian sentiments after a disaster, regardless of the outcome of a cost-benefit analysis.

Warning ethics. Warning systems are meant to serve the public good by saving lives and moveable property and by reducing injuries. Consequently, warning systems must influence and guide public behavior but not interfere with civil liberties. Debates over the ethics of warning systems have surfaced from time to time since the first assessment (White and Haas, 1975). For example, in the early 1970s a new alert device called DIDS was viewed as a warning breakthrough. The system activated radios to broadcast warning information. It was never adopted, however, because it was seen by many as a breach of privacy. Today, tone-alert radios are in place in many areas for some hazards, and the EAS technology is raising similar concerns about invasion of peoples' privacy.

Another frequently occurring issue of ethics has been whether warnings should simply advise the public about what protective actions to take or order them to take those actions. Contemporary consensus is that warnings should provide advice and recommendations. Sometimes this has meant standing by as some people decide not to evacuate and thus face almost certain death. For example, officials at Mount St. Helens knew that some residents refused to leave. Ethics questions continue to surface, and cannot be resolved readily.

Sources of information. Society is becoming exposed to greater amounts of information from an ever-larger number of sources, and people now receive warnings from more and more sources—some official, others not. Anecdotal cases of dual warnings in which an official source and another source are at odds have begun to surface. For example, in one case a local weather forecaster told people to ignore an NWS tornado warning—minutes later the tornado touched down; in another case a local television forecaster gave detailed storm track predictions on a street-by-street basis—far more detailed than could be supported by current scientific abilities. In yet another case a state agency provided hurricane storm track projections that differed from those issued by the NHC. Finally, a scientist made an earthquake forecast that was refuted by government seismologists.

These instances pose a basic dilemma for officials—how to get consistent and accurate information to the public given the fact that the government cannot regulate what unofficial sources say. The potential problems are clear: with inconsistent information people are less likely to believe a warning and more likely to waste time trying to get additional information to resolve inconsistencies, and many people will be less likely to take protective action in response to a warning.

Withholding warnings. The control and timing of public warnings continue to be thorny issues in emergency management. Several factors mentioned in the first assessment (White and Haas, 1975) still play a role in withholding warning information from an at-risk public. First, the unfounded but widespread belief that the public will become unnecessarily alarmed if warned about a low-probability but high-consequence event still prevails. This belief can sometimes result in reluctance to tell the public about an impending disaster until it is absolutely necessary, and even then some warnings are delayed, muddled, or suppressed. This reluctance to inform continues to affect both hazard detectors and emergency managers.

Second, sometimes warnings are still withheld because of concern over negative social and economic effects on the official or manager who will be responsible for coping with it and on society in general. In such instances there may be only a partial disclosure of information. This can seriously undermine warning effectiveness from the viewpoint of public protection. Additional information may well become public through unofficial sources, creating credibility problems for officials.

Multihazard Systems

If all hazards were the same, a generic warning system could be designed and used, but this obviously is not the case. There are six characteristics of hazards that affect one or more of the basic components of a warning system (detection, emergency management, and public response): (1) predictability relates to the ability to predict or forecast the impact of a hazard with respect to magnitude, location, and timing; (2) detectability refers to the ability to confirm the prediction that impacts are going to occur; (3) certainty is the level of confidence that predictions and detections will be accurate and not result in false alarms; (4) lead time is the amount of time between prediction/detection and the impact of the hazard; (5) duration of impact is the time between the beginning and ending of impacts in which warning information can be disseminated; and (6) visibility is the degree to which the hazard physically manifests itself so that it can be seen or otherwise sensed.

One kind of warning system will not work for all hazards or in all situations. But some events with similar characteristics may be able to use the same warning implementation strategy. In any case, hazard-specific knowledge must be incorporated into any warning system. A tiered scheme in which some components are shared across hazards but some are hazard specific may be the best approach. Any warning plan would address the warning system, organizational principles, and the basic public response process. The plan would then be specified or tiered into unique implementation procedures for each of the different hazard types that a community faces. Finally, unique hazard-specific information and site-specific conditions would be annexed to the plan.

Links to Sustainability

There is little doubt that improvements in prediction, forecast, and warnings have dramatically reduced deaths and injuries in the United States since the nation's first assessment (White and Haas, 1975). This is true for all hazards, but the same is unfortunately not true for many other parts of the world, particularly lesser-developed nations. Obviously, warnings can save lives and some moveable property and can reduce injuries. Beyond that, short-term (minutes to days) warning systems seem to have little direct bearing on sustainable development—or if links do exist, they have not yet been explored. Although they reduce deaths and injuries, warning systems have not been demonstrated to have any significant impact on reducing damage to social infrastructure or private property or on reducing economic disruption. In fact, short-term warning systems may hinder the movement toward sustainability by allowing long-term occupancy of marginal lands. For example, if people can return to occupy areas of high hazard because a warning system helped them avoid death or injury, the presence of a warning system may actually increase economic losses in the long run and jeopardize a sustainable economy. Again, the evidence is scanty and warrants further attention.

On the other hand, long-term warning systems (years to decades or longer) may have a major role to play in sustainable hazards mitigation. Long-term forecasts would provide local decisionmakers with some of the information needed to design their future communities. A certain amount of future losses would be part of any community's sustainable hazards mitigation plan because losses could never be reduced to zero. Long-term forecast systems would help redefine the risks that communities want to reduce, and information about the systems would be vital to the local planning process.

Conclusions

What has and has not been accomplished regarding warnings in the United States since the nation's first assessment was completed over two decades ago can be summarized in four phases:

1. *A national warning strategy*. The United States does not have a comprehensive national warning strategy. Warning practices are divided over different governmental entities and the private sector. For example, the new EAS being developed by the Federal Communications Commission is coordinated with the NWS but not with other public or private providers of prediction and forecast information, and different local communities vary greatly in the quality and likely effectiveness of in-place warning systems. The nation needs to develop a comprehensive model for warning the public, provide it to local communities along with technical assistance, and even out the degree of protection provided by warnings systems for all citizens.

2. *Improving warning systems*. Public alert systems can be improved with new hardware and technology, but diffusing existing technology and warning preparedness knowledge is a much bigger problem in the

nation today. Further technological advances will only increase the gap between practice and the state of the art. An exception would be the development of very inexpensive equipment that could be easily installed and maintained and that could rapidly alert and notify the public. The diffusion of SAME-enabled EAS warning devices into American households will likely be a slow process. Even when such devices are commercially available, few low-income residents will have them. Furthermore, the EAS cannot provide outdoor warnings.

Improvements to local warning systems are needed on two fronts. The first is the dissemination of information on low-cost or no-cost improvements. This includes improved procedures and management practices, which can result in a much better warning system without major financial expenditures. The second is the provision of funds for better communications and warning system equipment. Few communities have the funds to install new equipment and so will require technical assistance and/or cost sharing. Better local management and decision-making about the warning process are more critical than promoting more advanced technologies, although both would help. The most sophisticated equipment is relatively useless unless it can be used properly.

3. *Knowledge gaps*. The ability of a system to provide timely public warnings begins with monitoring the environment to detect hazards. Detection technology is readily available for some hazards but is only in a state of development for others. Technological capabilities also vary with respect to the amount of lead time provided and the "noise" in the detection signal. Monitoring technologies, which provide ongoing data about the physical system, are of equal importance. Again, monitoring coverage is fairly good for some hazards and poor for others, such as hazardous materials accidents. Complete coverage of the entire U.S. land mass, or even of all populated areas, has not been achieved for any hazard.

4. *Improved predictions, forecasts, and warnings*. Most advances in prediction and forecasting since the nation's first assessment in the 1970s have come from better monitoring, instrumentation, data collection, and data processing. Some of these have resulted from advances in theories and models, but no radical theoretical breakthroughs have occurred in the past 20 years. The ability to deliver warnings to the public—which means a thorough integration of the scientific component with an effective delivery mechanism—has a checkered record. Table 6.3 estimates

TABLE 6.3 Improvements in Prediction, Forecast, and Warning Integration

Hazard	Prediction/Forecast	Warning Integration
Flood	Some change	Not much change
Hurricane	Major changes	Major changes
Tornado	Some change	Not much change
Drought	Not much change	Not much change
Fire	Not much change	Not much change
Avalanche	Not much change	Not much change
Earthquake	Not much change	Major changes
Volcano	Some change	Not much change
Tsunami	Not much change	Not much change
Landslide	Some change	Not much change
Nuclear power	Major changes	Major changes
Hazardous materials/chemicals	Major changes	Not much change

the relative improvement in prediction/forecast and warning integration over the past 20 years. Even given the natural uncertainty in the behavior of hurricanes, improvements in prediction and forecasting capabilities and the ability to graphically present scientific information and warnings for that hazard have been exemplary. This is the case for nuclear power as well, although the impetus for that improvement came from regulatory requirements. Some advances have been made in predicting, detecting, and forecasting floods, tornadoes, volcanoes, landslides, and chemical accidents, but these improvements have yet to be integrated into warning dissemination. Earthquakes represent a unique case: while dramatic improvements have been made in integrating the warning process, our ability to predict earthquakes has not improved. Finally, four hazards have shown little change in either prediction/forecast or warning integration: droughts, wildfires, snow avalanches, and tsunamis. There is much room for improvement in the next 20 years.

ENGINEERING

Although efforts to reduce mortality rates from hazards and disasters over the past several decades have largely been successful, there is no way to determine how much of that reduction is attributable to state-of-the-art engineering approaches to individual hazards or infrastructure. There is no doubt that improvements in the constructed environment can minimize damage and thus economic losses on a structure-by-structure basis, but aggregated data on economic damage, damage avoided, residual damage, and a wide range of other losses are notoriously incomplete and unreliable. Furthermore, there is no measure of the extent to which reliance on engineering technology may have encouraged the process of ever-more-expensive development in hazardous places.

Nevertheless, carefully engineered buildings and infrastructure will be essential to the future disaster resiliency of all localities. The task will be to accurately assess all of the hazards involved and balance them against the benefits to be gained, according to a given community's preferences. Localities will need to reach their own decisions about the level of hazard they believe is appropriate to their situation and balance that with the other components of sustainability—the quality of life they want, the kind of environment they want future generations to have, and so forth. Part of that decisionmaking process will be to determine the extent to which an engineering solution will reduce future hazard, for how long, against what magnitude of extreme event, at what economic cost, and at what environmental price. This "total risk management framework" will be complex, unique to each locality, and probably changing continuously.

Engineering codes, standards, and practice have evolved and been promulgated in the United States for all natural hazards. For buildings and lifelines these codes vary widely based on local perceptions of benefits, costs, and risks. Affordability is a key factor in whether codes and standards are changed. Thus, the establishment and enforcement of codes and standards are a problem of social choice and are not based exclusively on technical feasibility. Buildings are complex combinations of the basic foundation and structure, plumbing, electrical, heating, ventilation, air conditioning, and ancillary systems. The structural aspects of a building consider earthquake, high-wind, flooding, and related disaster loads.

Infrastructure (sometimes called "lifelines") includes all of the structural components that provide connections among human developments, such as transportation networks, communications networks, electric power lines, gas lines, water supply systems, hazardous materials storage facilities, and drainage and water treatment systems. For infrastructure the engineer integrates all of the hazard impacts as part of the design and management. A recent report on the impacts of the 1994 Northridge earthquake presents a good summary of the impacts of this event on critical lifelines (Schiff, 1995).

Earthquakes

Historically and currently, life safety is the first goal of the seismic resistant design of structures. Reducing the loss of function of a structure or preserving property are secondary important goals. Since the first assessment was completed, observations of the effects of earthquakes have revealed that much is not yet known about the effects of earthquakes. Most estimates of ground motions are uncertain by a factor of two or more. Earthquake magnitude, distance from the source of energy release, location of a structure relative to the fault, and site response are each important factors in determining impacts. Earthquakes each have their own characteristics, e.g., variations in frequency content, accelerations, and duration. Building performance varies widely due to these differences; consequently, performance of a structure in one earthquake does not predict performance in another earthquake (California Seismic Safety Commission, 1994).

The major factors that influence earthquake-induced damage to structures include the characteristics of the site, the structural system itself, and its configuration relative to the site. These factors have as much influence on damage as do the size of an earthquake or distance to a fault. Most of what is known about the performance of structures in earthquake results from actual experience.

A related but separate issue is damage to the nonstructural elements of buildings since such damage impairs functionality. In fact, most life loss and injury in earthquakes is caused by the failure on building contents—for example, toppled bookcases and furniture, broken or fallen pipes, and collapsed suspended ceilings. Building contents frequently fail in earthquakes even when the building that houses them performs well.

Another important issue is the mitigation of the effects of earthquake hazards on lifeline systems. Most current efforts to mitigate impacts seek to design for operational flexibility in the face of lifeline service interruption; for example, storing water, electrical generators, and wireless communication devices. Lifeline replacement or constructing redundant lifelines are often too expensive to implement in most of the nation's communities; although noteable exceptions exist, for example, Pacific Gas and Electric Company's lifeline replacement program in northern California.

Significant current and future shifts in the nation's approach to earthquake engineering provide a clear link to sustainable hazards mitigation. These shifts include performance based seismic design which enable building owner decisions about the level of seismic resistance put into a building; for example, an owner can choose to go beyond life safety to include damage control to maintain operations after an earthquake. A second example is the clear call for increased laboratory testing of both structural and nonstructural building elements.

Floods

Flood control is a classic case of the evolution of engineering design standards in an area where a wide variety of structural and nonstructural controls have been used over a long period of time. Engineers have long recognized that flood protection cannot be provided for every conceivable flood. The methods previously used made some gross assumptions as to the uncertainty in hydrological and hydraulic calculations, the level of acceptable risk, and the benefits derived from flood control. The U.S. Army Corps of Engineers recently developed new methods for evaluating uncertainty in flood control evaluations (National Research Council, 1995). The methods explicitly estimate uncertainty in the hydrology, hydraulics, and economics of a planning study. The new methods bring these uncertainties to the forefront of the process used to evaluate various forms of flood control. Local decisions and analysis may now take into consideration uncertainty in engineering calculations, uncertainty in estimations of naturally occurring random events (i.e., precipitation, runoff), and future economic uncertainty.

Although these new methods do not yet include a cross-hazard holistic approach to decisionmaking, they may be a step in the right direction by bringing previously "assumed away" uncertainty into the decisionmakers' arena. In addition, very different flood control solutions may be weighed against each other in a consistent manner. For example, an improved levee system could be compared to a floodproofing program, where the probability of net benefits for each project could be weighed.

Dams and associated reservoirs serve multiple purposes, but they also increase hazards downstream if they fail. Engineers have developed sophisticated methods to evaluate alternative failure mechanisms for dams, including foundation conditions, materials, and initiating mechanisms such as floods, earthquakes, and landslides. Dam safety evaluations use relatively sophisticated methods of risk analysis, including comparing risks across hazards.

Hurricanes

Hurricanes can cause significant loss of life and economic damage. In the case of Hurricane Hugo, which hit the coast of South Carolina in September 1989, engineers had been recommending for 20 years that buildings and other structures be designed to withstand hurricane conditions with recurrence intervals of 50 to 100 years. Even though Hurricane Hugo was not that severe an event, the area suffered major damage. The major impact on lifelines was the failure of the electric supply system, which collapsed in winds of only 70 mph. Only 23 percent of the residents in the Charleston area had power eight days after the hurricane, and it was two to three weeks before power was restored in some rural areas. The failure of the power system caused problems with other infrastructure. Work by the telephone companies to move utilities underground had improved the reliability of the telephone system. Properly designed structures fared very well.

In contrast, Hurricane Andrew in 1992 caused relatively little damage to lifelines, although above-ground utilities, especially electric power lines, performed poorly. The major damage was to residential structures from the failure of roofing materials, doors, and windows, which led to weather penetration and significant damage. Nearly 100 percent of the manufactured housing was destroyed. Overall, the vast majority of monetary damage to buildings was due to water penetrating the buildings, not structural failure.

Winds

During the past 25 years, organizations around the world have documented the performance of buildings in wind storms on a comprehensive and systematic basis. Professional and academic institutions in the United States that documented wind damage include the American Association for Wind Engineering (formerly the Wind Engineering Research Council), the Institute for Business and Home Safety, Texas Tech University, Clemson University, Texas A&M University, and the National Research Council. This information provides insights into the actual performance of buildings in wind storms. The general observations on building performance and identification of problem areas made below are based on these field investigations.

The structural integrity of contemporary high-rise buildings (six stories and higher) should be maintained in wind storms. However, roofs and walls are susceptible to damage. Industrial buildings with frames of heavy steel and reinforced concrete generally maintain structural integrity in wind storms. But overhead doors, windows, and light-weight metal wall or roof panels are susceptible to failure.

Low-rise commercial buildings such as retail stores, schools, warehouses, and motels sustain extensive damage in severe wind storms. The level of damage depends on maintaining the integrity of the structure. If the structural frame collapses, there is total loss. Light steel frames, unreinforced concrete block walls, and timber frames, which are expected to maintain structural integrity, sometimes fail. The result is collapsed roofs and walls and possibly total collapse of the building, perhaps causing death or injuries to any occupants.

Single- and multiple-family (up to four units) dwellings, which are generally not engineered, experience a large amount of damage in wind storms. If not properly anchored to the walls, the roof lifts up, resulting in extensive damage, including subsequent collapse of walls. Residential buildings generally have several intersecting walls that create a small interior space; this interior space provides a high degree of protection to the occupants even when the rest of the building collapses.

The first national consensus standard that contained wind load provisions was American National Standards Institute A58.1-1955. There were very few changes over the years. The 1982 version of ANSI A58.1 contained a new basic design wind speed map and attempted to clean up the ambiguities and simplify the procedures of prior versions. Model building codes began to acknowledge the ANSI A58.1 standard and accept its provisions. The next revision came in 1988, when the American Society of Civil Engineers took over maintenance of the standard and it became known as ASCE 7-1988.

After Hurricane Andrew in 1992, code bodies and municipalities looked for more rigorous codes, and ASCE 7-88 was recognized as such. Finally, ASCE 7-95 was published in 1995. It contains a new basic wind speed map based on three-second peak gust wind speed rather than the antiquated fastest-mile wind. Model building codes are in the process of adopting ASCE 7-1995. The ASCE 7-95 code is based on extensive full-scale and wind tunnel studies of wind effects on structures. The standard recognizes the high localized pressures at eaves, ridges, and wall and roof corners. It accounts for internal pressure when there are openings in the building.

Landslides, Land Subsidence, and Expansive Soils

The main option for prevention of landslide damage through engineering is careful site preparation in the form of grading and attention to drainage, followed by improved construction practices to minimize instability of the slope. Some engineering solutions are available to minimize subsidence damage to structures and lifelines, including use of geofabrics and earth reinforcement for slabs and roads, proper log grading, and foundation and utility supports. Mines and other subsurface cavities can sometimes be backfilled. Engineering mitigation options for expansive soils include removing them, applying heavy loads to offset swelling pressure, preventing access of water, prewetting, and stabilization with chemicals.

Snow

Mitigation of the snow load hazard for new building construction is fairly straightforward. It involves the design or selection of structural members having adequate strength to resist the roof snow loads given in building codes and load standards. Use of roof loads intended to have a mean recurrence interval of about 50 years, in combination with structural safety factors, is thought to result in structures with an acceptably low probability of structural distress or collapse.

Mitigation of the snow load hazard for existing construction is more complicated. Assuming that the initial structural design was proper, problems can arise from deterioration in structural capacity or larger-than-expected loads. Currently, there are no commonly recognized government requirements for periodic inspection or upgrades of privately owned facilities. As a result, mitigation of existing structures is typically owner driven. For a roof it can take the form of structural strengthening of vulnerable elements or other more innovative approaches, particularly for drifts.

CONCLUSION

All of the mitigation tools described in this chapter are essential for a future that embraces sustainable hazards mitigation. The challenge for future researchers and practitioners will be to combine these tools in the most effective and economical ways to achieve community or regional goals of sustainability. Interestingly, the tools for sustainable hazards mitigation reviewed in this chapter are the same ones that have always been available for natural hazards management. What is needed is a shift in emphasis. The sustainability approach to hazards calls for increased use of wise, long-term land-use approaches, enhanced production and use of long-term hazard forecasts in community decisionmaking, insurance as a vehicle to foster mitigation efforts through location decisions and construction practices, and engineered approaches and building codes that go beyond life safety toward protecting the functionality of structures that localities choose to locate in harm's way.