8

Risk Assessment

INTRODUCTION

Thus far, we have discussed hazards as they exist in nature and as they affect and are affected by human perceptions, actions, and institutions. However, there is another element that is crucial to our understanding of natural hazards and the ways we seek to manage them: that of risk. The terms *risk, risk analysis,* and *risk assessment* are pertinent to many fields besides natural hazards research and encompass many interests, including scientific calculations of probabilities of occurrence, expert evaluations of possible consequences, laypersons' understanding of risk, and various types of risk management. The literature on risk is extensive and diverse (Montz & Tobin, 2012, 2013; Slovic, 2000; Tobin & Montz, 2009), with a sizable component devoted to aspects of risk analysis (Covello & Mumpower, 1985; Flynn, Slovic, & Kunreuther, 2001; Jaeger, Renn, Rosa, & Webler, 2001; Linnerooth-Bayer, Löfstedt, & Sjöstedt, 2001). In many ways, risk sits at the core of disaster management, and hence it is crucial that we understand the basic concepts if we are to make meaningful decisions regarding mitigation strategies (see, e.g., Fra Paleo, 2015b). We cannot include all facets of risk in a single chapter, so our focus here is on the definitions, issues, and management of risk from a natural hazards perspective.

What Is Risk?

To understand risk and uncertainty, we need to examine hazards' physical processes in conjunction with the human use system. This relationship is illustrated in Figure 8.1, which juxtaposes various processes of the physical environment (e.g., events' frequency, magnitude, duration), on the left, with processes of the human environment (e.g., social norms, coping mechanisms), on the right. Of course, in reality the two major spheres are hardly entirely separated because their components inevitably interact with and influence one another. Furthermore, the relationship is complex, with causality reflecting the interaction and the constantly changing relationships of many of the variables. As indicated in the lower (dash-lined) box, however, the figure fails to capture the dynamism of risk (represented as the central focal point in the figure), which is invariably the key concern almost by definition of any risk manager.

It is the different conceptions of natural hazard risk that help shape our perceptions of and responses to natural hazards. However, to understand risk and vulnerability fully, we need to pay attention to the appropriate scale of analysis (Birkmann, 2007). We can, for instance, look at risks at the level of the individual, as in the case of deaths and injuries from disasters (Ellidokuz, Ucku, Aidin, & Ellidokuz, 2005), or at the community or national level of exposure. In fact, it is the perceived level of disaster risk that is a critical element in whether communities (or individuals) take action to reduce it, and, conversely, it is the organization of society and place together that helps determine the degree of risk. In this respect, Pelling (2012, p. 146) points out that "differences in urban vision go some way to explaining why it is that so many urban risk governance problems appear intractable." There are many levels of analysis that must be addressed. This is not to argue that rural risk is not also problematic, as shown by Davies, Guenther, Leavy, Mitchell, and Tanner (2009). Overriding much

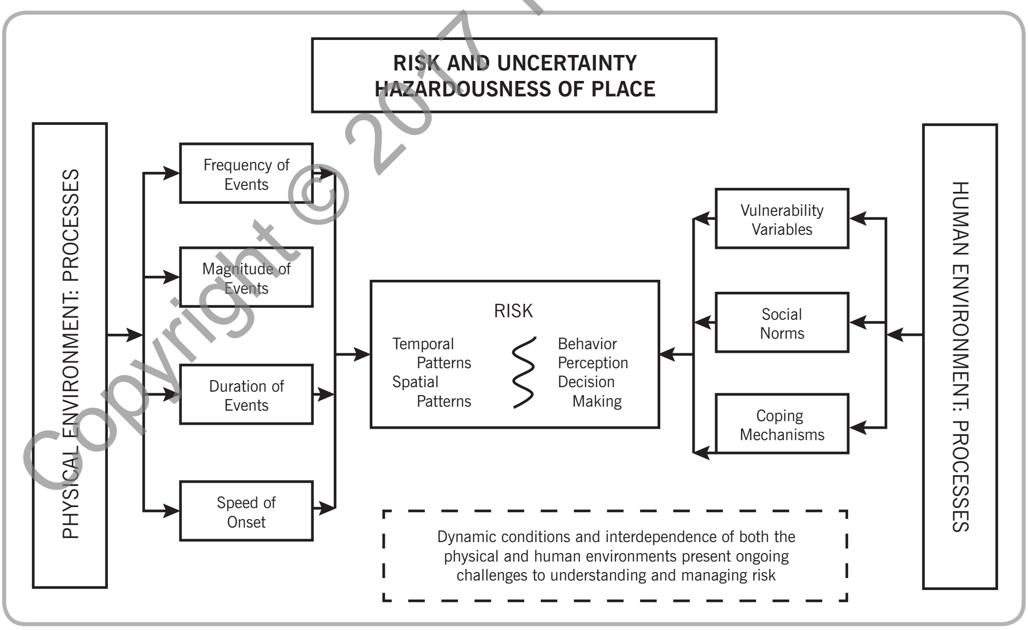

FIGURE 8.1. Model illustrating the relationship between the physical and human environments in determining risk. The interactions both within and between each subsystem are ever changing, so risk is ever changing as well.

of this are inherent cultural traits and traditional practices that can both mitigate and exacerbate risk (Hewitt, 2012). Thus, we need to understand risk not only in technical terms but also in terms of how it is perceived by those in hazardous areas and how it is managed (or not) through risk mitigation, sharing, and avoidance strategies. To achieve that level of understanding, we need to explore some background information on how risk is determined and consider what we already know about its natural and technological sources.

Hazard Risk

In its simplest form, risk is an outcome of geophysical forces that can be examined through temporal and spatial lenses (Tobin & Montz, 2009). We can certainly categorize hazards temporally by observing their frequency, seasonality, and/or diurnal occurrences. Hurricanes and tornadoes, for example, might be expected more frequently at particular times of the year, thunderstorms at certain times of the day, and so on (as detailed in Chapter 3). At the same time, there is a spatial dimension to risk, with many events defined by location. For the most part, earthquakes and volcanoes are found in specific zones, hurricanes make landfall in certain regions, and even weather events such as blizzards and tornadoes are somewhat spatially defined. Mapping hazard zones along with the probability of the occurrence of events is a useful exercise that adds spatial patterns to this simple risk model.

In Chapter 3, the probability of recurrence of particular geophysical events was assessed through historical trends. Lengthy historical records make it possible to determine the probability of certain-sized events occurring in any given year. However, defining risk as the product of probability of occurrence and magnitude is to reduce risk to a technical calculation; it combines the two elements of risk in a logical, mathematically sound manner, thus yielding a means of comparison. One drawback to this concept, though, lies in the fact that identical "risk" values may lead to significantly different outcomes—because they do not indicate the number of people exposed to a hazard or the losses expected from a specific event. A straightforward measure of occurrence multiplied by magnitude could result in similar values for high probability–low consequence and low probability–high consequence risks. For example, an earthquake of magnitude 7.5 on the Richter scale might have a return period of approximately 100 years at a specified location (i.e., a 0.01 probability, or 1% chance, of occurring in any given year). According to the formula, the risk could be described as 0.075 (i.e., 7.5×0.01, via simple multiplication). Let us assume also that a 3.75 magnitude earthquake has a 0.02 probability (that is, a 50-year event), which likewise translates into a risk factor of 0.075. Similarly, an earthquake with a 0.05 probability and a magnitude of 1.5 also would have a risk factor of 0.075. Despite seemingly identical technical ratings (based on simple quantitative methods), these events would probably have different impacts. Thus, attempting to reduce hazard risks to a neat mathematical formula—or even to purely geophysical processes—is erroneous from a natural hazards perspective; there is considerably more than that to hazards. In fact, risk is just a part of hazards, and the two terms are by no means synonymous. Risk, though, is an important component of hazard analysis, and risk analysis forms an important subdivision of the study of natural hazards.

In this book, we have been concerned with society's views and perceptions because they influence attitudes, actions, and ultimately vulnerability. Hence, Whyte (1982) suggested altering the risk formula from:

$$\text{Risk} = \text{Probability of occurrence} \times \text{Magnitude}$$

to

$$\text{Risk} = \text{Probability of occurrence} \times \text{Magnitude}^{n}$$

where n represents social values.

Whyte's modification is a step forward, allowing for inclusion of social concepts of risk, and it consequently recognizes variations in perception in different contexts. The difficulty, of course, lies in trying to put a value on n. Nonetheless, it expands our view beyond a narrow technical measure of risk to one that recognizes the importance of different social and cultural interpretations and outcomes, and, along with the formula presented earlier, illustrates the numerous ways risk can be conceptualized. As we have emphasized, disaster outcomes can be and frequently are changed, most obviously through mitigation. Such actions as retrofitting buildings to withstand shaking, refining emergency response systems, and planning recovery procedures change the nature of the earthquake risk because they reduce adverse consequences and change people's perceptions. It has been argued that when n is sufficiently high, mitigation measures are sought in an attempt to lower the ultimate value of n. For instance, if the magnitude of the 7.5 earthquake event were squared, then risk would rise from 0.075 to 0.5625.

Refining this perspective further, we should incorporate elements of disaster impacts; to get a better assessment of hazard risk, details on vulnerability must be incorporated into the analysis. Statistically, this relationship can be expressed as

$$\text{Risk} = \text{Probability of occurrence} \times \text{Vulnerability}$$

This equation, of course, raises the additional question: What is vulnerability, and how do we measure it? This relationship was used by Van Dissen and McVerry (1994) to evaluate earthquake risk in New Zealand. They defined *probability* as the likelihood of an earthquake's occurring (based on results of a seismicity model) and *vulnerability* as the damage potential for property (measured through use of a damage ratio). This certainly encapsulates elements of both the geophysical forces and human dimensions and is valuable in broadening our understanding of risk, but both components are still somewhat limited. The formula fails to incorporate differences in population size and density (or what might be termed *exposure*) as well as communal adjustments undertaken to minimize losses. Mitchell (1990) used a similar approach but modified the formula, conceptualizing hazards as a multiplicative function of risk, exposure, vulnerability, and response:

$$\text{Hazard} = f(\text{Risk} \times \text{Exposure} \times \text{Vulnerability} \times \text{Response})$$

where risk is the probability of an adverse effect, exposure is the size and characteristics of the at-risk population, vulnerability is the potential for losses, and response is the extent to which mitigation measures are in place.

In combination, these elements serve to explain differences in hazardousness from place to place and from time to time. If we adopt Lowrance's (1976, p. 8) definition of risk as "a measure of the probability and severity of harm" and combine it with Mitchell's conceptualization, it is not difficult to imagine different disaster scenarios. At one extreme, an event with a low probability of occurrence might create considerable losses, such as occurred with the Indian Ocean tsunami in 2004. The geophysical event was low-risk in terms of the expected frequency of the earthquake and tsunami, but the high concentration of people settled along the coastlines of India, Indonesia, Malaysia, Sri Lanka, and Thailand demonstrate the need to incorporate exposure into the risk equation (Karan & Subbiah, 2011). This would likely be the case for any unprepared but densely settled locality. At the other extreme, perhaps with relatively constant (high) probabilities of occurrence, different measures of vulnerability will significantly affect the estimated intensity of a hazard, as was apparent with the 1995 earthquake in Kobe, Japan, and tropical storms in Bangladesh (discussed in Chapter 1). At a given risk, a hazard may be lessened if the vulnerable population is protected by mitigation measures or has the financial or other resources to recover from loss. Risk, then, as a concept depends not only on geophysical processes but also on the levels of exposure, vulnerability, and response.

Overall, risk can be viewed theoretically as existing on a two-dimensional plane for any specific location, the extremes of which are high probability–low consequence and low probability–high consequence risks (see Figure 8.2). An example of the former might be a thunderstorm in Florida, while a category 5 hurricane making landfall near Miami Beach might illustrate the latter. Certainly, any number of natural and technological hazards could be depicted at different points on the plane. The two examples serve to illustrate extremes at a given location. On this figure, the Indian Ocean tsunami would be low probability of occurrence but with very high consequences, whereas a violent volcanic eruption along the Aleutian Islands might have a high probability but the consequences will be low, at least in terms of human impacts.

To facilitate risk comparisons among nations, the United Nations Development Programme (UNDP) has developed a Disaster Risk Index (United Nations Development Programme, 2004). The index includes measures of physical exposure to hazards, limited in this instance to floods, tropical cyclones, and earthquakes, and identifies how vulnerability indicators might contribute to the risk. Based on data from 1980 through 2000, the average risk of death from these types of events was calculated, controlling for the country's economic level. It is apparent from these data that losses are correlated with a nation's development status, with low-income countries experiencing higher levels of death than high-income ones (see Figure 8.3). At the global scale, therefore, patterns emerge as to risk and exposure that are not related simply to the physical environment.

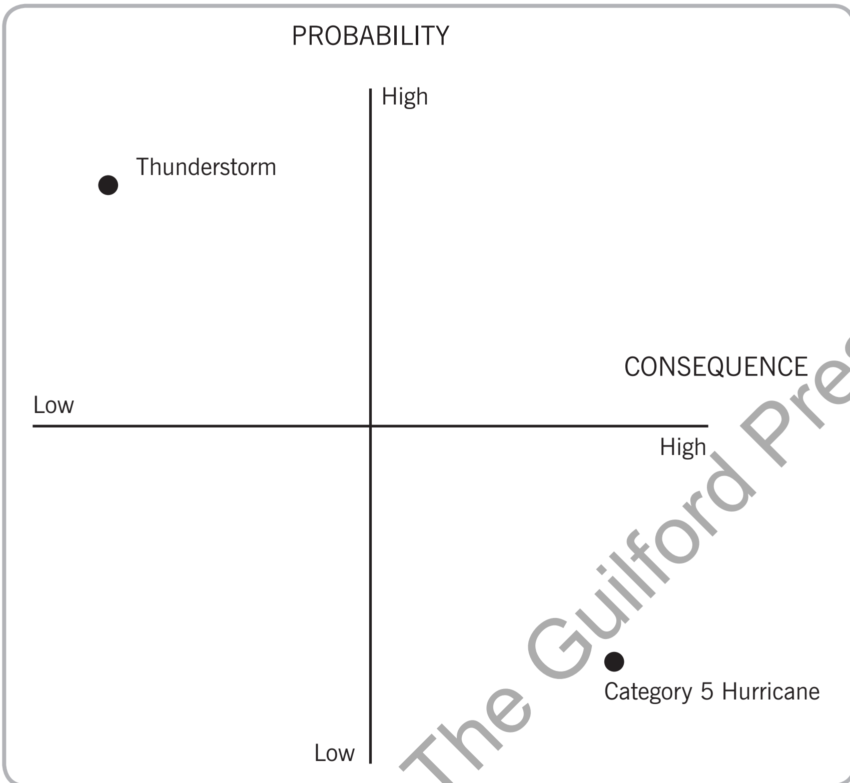

FIGURE 8.2. Relationship between an event's probability of occurrence and the extent of probable consequences. Different hazards would occupy different points on this diagram; the two depicted here illustrate potential extremes.

Wisner and colleagues (2012) outline yet another framework where disaster risk is also defined as a product of hazard and vulnerability. Recognizing that this definition itself is somewhat vague, at least in its practical application, they clarified the relationship, stating that "disaster risk is a function of the magnitude, potential occurrence, frequency, speed of onset, and spatial extent of a potentially harmful natural event or process (the 'hazard'). It is also a function of people's susceptibility to loss, injury or death" (p. 24).

Adding "susceptibility to harm" and "protective action" to the mix, they proposed that

$$\text{Disaster risk} = H \times [V/C - M]$$

where H represents hazard, V is vulnerability, C is the capacity for personal protection, and M is larger-scale risk mitigation through preventive action and social protection.

Thus, risk is only part of the notion of a hazard, but we must understand risk in order to grasp the complexities of hazards. Just as risk is only one component of

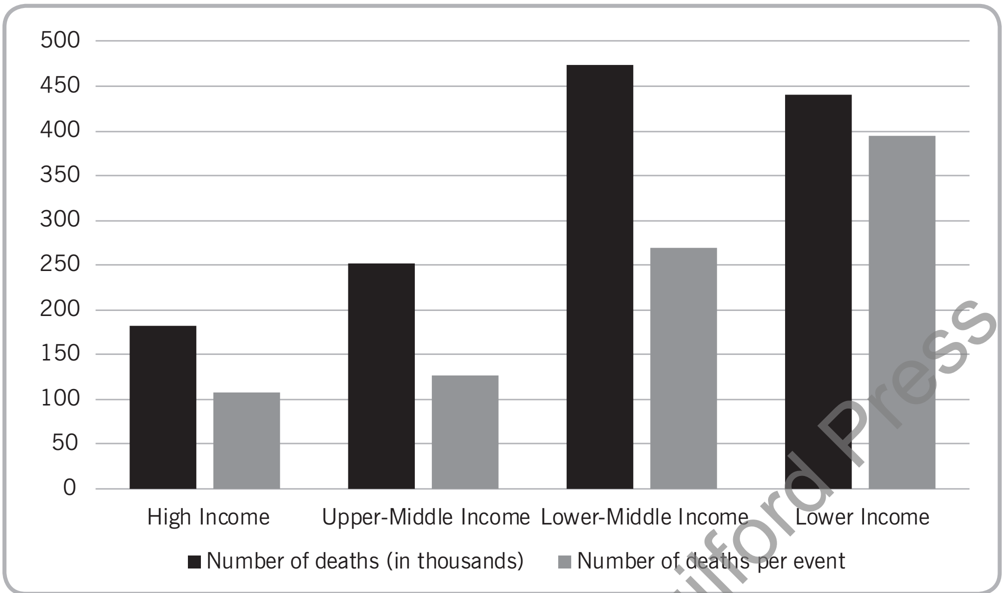

FIGURE 8.3. Relationship between economic development and deaths from disasters. Both the absolute and relative number of deaths from disasters is greater for lower income countries. From International Federation of Red Cross and Red Crescent Societies (2014c).

hazards, risk also is complex. It comprises two elements that must be considered both separately and together, namely, the choice of action and the outcome, with the latter encompassing both a probability and a consequence. The two in combination—that is, choice of action and outcome—create different degrees of uncertainty.

Choice of Action/Survivors of Circumstance

Human life requires choices among actions that are linked inextricably to risk (Dinman, 1980). Every decision and resultant action, whether voluntary or involuntary, is an intricate part of human existence that ultimately exposes people to risk. In reality, no one is ever completely safe no matter what decisions are made, although clearly some individuals are safer than others. For example, inhabitants of squatter settlements on the unstable slopes of Lima, Rio de Janeiro, and Hong Kong or on the floodplains of Santiago, Karachi, Caracas, Delhi, Manila, and Mexico City (Torry, 1980) are obviously more vulnerable than people residing in substantial dwellings in less hazardous environments. In contrast, choosing to purchase property on a steep, unstable cliff along the California coastline represents a conscious decision to take advantage of the scenic vistas as weighed against the potential costs of landslides. It should be stressed, however, that the decision to reside in a particular area is not necessarily made freely, but is usually determined by socioeconomic forces that often are beyond the control of individuals. Those residents of the squatter settlements are essentially victims of socioeconomic circumstances. This extends to many other individuals who find themselves at risk through prevailing conditions that exist because others made decisions perhaps years earlier. Thus, risk involves choices, but those at risk are not always the ones who make (or made) the choices. As discussed by Slovic (1987), voluntary risk, as exemplified in the Californians seeking scenic views, is much more acceptable than involuntary risk, as typified by the floodplain dwellers in Santiago.

Of course, many decisions place people at risk. People face risks every day, many apparently voluntarily, such as choosing to drive (rather than walk) to work, or to smoke cigarettes, or to live alongside eroding shorelines. However, decision makers may find their choices inhibited by various economic, cultural, social, political, and even religious constraints. Furthermore, even some voluntary risks may not be deemed fair in the eyes of society. Sagoff (1992) contrasts the risk associated with purchasing a lottery ticket with that of owning a house adjacent to a chemical factory. Although both situations are risky, the lottery ticket holder cannot expect society to reimburse any losses, while it is generally agreed that the homeowner should not be held accountable for his or her loss if an accident occurs at the factory. The same should apply to those residing in hazardous areas through no real choice of their own.

Knowledge of the available choices is an important factor in choosing one's course of action. Although the relationship is more complicated than suggested here, it is important to recognize that risk involves choice. Who makes that choice, based on what information, for whom, and with what results are all crucial concerns when answering questions about why people continue to occupy hazardous areas. Obviously, these are complex questions.

Outcomes: Probability and Consequence

Besides choice, some attention must be given to outcomes of decision making. Those who elect to live in hazardous areas may not fully appreciate the true risks involved. While their initial choice may have been voluntary, their knowledge of potential outcomes may have been incomplete. For example, the retiree who becomes a homeowner in Florida may be unaware of the seriousness of threats from hurricane-force winds, storm surges, or rising sea level locally. Even with this knowledge, such a decision may be perceived as internally rational by the individuals concerned. If the person relocating expects to live in the hazardous zone for only a limited time (say, 5–10 years), then his or her lifetime risk is less than that for someone planning to live there for 50 years. Thus, risk must also account for exposure. Of course, this does not mean that a major tropical storm will not hit the area during his or her first year of residency.

Predicting outcomes is not easy for either individuals or society. Outcomes have a number of characteristics that can vary significantly, depending (among other things) on the geographic location and the time of occurrence of the event. For example, take the physical aspects of a hazard; the magnitude, timing, and extent of a geophysical event influence the decision making of the individuals involved. Although risks associated with natural hazards are not usually viewed as positive, if the timing is right, the flooding of agricultural lands can actually increase fertility without damaging the crops. However, a flash flood calls for immediately vacating the hazard zone, and failure to respond appropriately can result in death. Over 140 people died in the Big Thompson Canyon in 1976, many because they made the wrong decision to try to outrun the flood in their automobiles (Gruntfest, 1977). The pattern was repeated in 2013 when flash floods again cascaded down several Colorado canyons, destroying homes and tearing up roads in their path. During the intervening years, more people had moved into hazard-prone areas, and frequent wildfires had further exacerbated the flood risk by removing vegetation that would hold some water in place (Gochis et al., 2014). Actions can have negative or positive outcomes that affect the element of risk; those individuals who attempted to drive down the canyon increased their risk, while those who climbed to safety reduced theirs. Societal decisions also can have positive and negative outcomes; building a sea wall to prevent sea surges from hurricanes, as was done in Galveston, Texas, and New Orleans, Louisiana, encouraged development in purportedly newly "safe" zones, thereby ultimately placing more people and property at risk. As discussed in previous chapters, this phenomenon is commonly referred to as the levee effect.

Thus, there is uncertainty associated with outcomes, an uncertainty founded not only in the physical dimensions of hazards but also in any decision making that occurs. For example, we cannot guarantee that a disaster of a particular magnitude will occur at a specific time or place; for most hazards, it is not possible to forecast events so precisely. Similarly, although we can identify some areas as prone to particular geophysical events, we cannot be confident that any area is completely free from a specific hazard (as discussed in Chapter 3). Human behavior further complicates the range of possible outcomes, such that the extent of property damages or number of lives likely to be lost cannot be predicted with precision prior to an event.

Nonetheless, there exist some projections for deaths from potential events. In California, scenarios for earthquakes of different magnitudes at different times of day have been used to estimate the number of probable fatalities (FEMA, 1980; U.S. Department of Commerce, 1973). Now HAZUS enables authorities to make very rough estimates of risk associated with various magnitudes of earthquakes. However, similar models do not generally exist for other hazards at other places (as discussed in the preceding chapter). To counter this omission, we must think in terms of the probabilities of outcomes or consequences. For example, it is possible to calculate the likelihood of dying from a particular action or event (refer back to Table 1.4 in Chapter 1). However, while these numbers are useful in comparing risks, they are based on the same outcome (death) and do not include a temporal component; without it, such figures can be grossly misleading because exposure is not considered. For example, the risk of a worker being killed in a quarry may be 1 in 3,100 per year at any given time, but that risk increases to 1 in 80 over a 40-year work career (Dinman, 1980). Similarly, the risk of dying from an earthquake is quite different if one lives in Iran or in California. In general, death rates are meaningless without qualifying information on the factors that might affect one's exposure, such as one's location, health and socioeconomic status, age, occupation, gender, and all the other vulnerability measures discussed earlier.

Uncertainty

One difficulty that pervades all consideration, evaluation, and analysis of risk is the level of uncertainty with which we must contend. Indeed, uncertainty is inherent in all aspects of risk. It lies in the probabilistic nature of occurrences, in outcomes, and in the efficacy of various choices. Uncertainty is problematic for several reasons. First, because it is found in all elements of risk, reducing it is not a simple matter; different approaches are required for different elements. Second, the level of uncertainty is not the same for each element or for all hazards. Third, people differ in their tolerance for uncertainty, and their differences are seen in the elements of risk. For instance, some individuals may be more comfortable with uncertainty of occurrence than with uncertainty of outcome, while for others the reverse may be true. In both cases, their decisions would reflect these differences. Finally, uncertainty may be increased by combined risks (discussed later in this chapter). As the risks become more complex, uncertainty increases, as do all the problems just noted. Some researchers have addressed such uncertainty directly. For example, Wilson and Crouch (1987) calculated that the risk of getting cancer from drinking water at the U.S. Environmental Protection Agency's chloroform standard is 6×10^{-7}; however, this assessment is subject to an uncertainty level by a factor of about 10. Similarly, they reported that the risks of developing cancer from cigarette smoking, background radiation, and eating large quantities of peanut butter also had uncertainty levels by a factor of 3. These are not insignificant levels of potential error, naturally calling into question how accurate risk projections in other areas of human life might be.

Uncertainty plays an important role in our estimations of risk, definitions of which risks we are willing to face, and our ability to understand what risk means. Individuals often reduce their personal vulnerability by misinterpreting probabilities. For example, an event of low probability may be completely negated or perceived as a cyclical event that will not occur again in a certain number of years; thus, many individuals feel safe immediately after a 100-year flood, as discussed earlier. For those charged with managing risk, however, uncertainty is a complication that must be recognized and addressed.

Risk Communication

In the discussion above, knowledge of choices and outcomes surfaced as an important consideration. Indeed, the extent to which people understand the nature of a given risk and the choices available to them can affect the level of risk to which they are exposed. Experts and the media are the major sources from which the public derives its knowledge of risks. However, experts tend to either over- or underestimate the public's ability to evaluate risk and choice. In either case, the result is the same, namely, appropriate information in an understandable form is not communicated to the public (see Mulilis, 1998, for a review of the literature in this area). As Morgan (1993, p. 4) comments, "If anyone should be faulted for the poor quality of responses to risk, it is probably not the public but rather risk managers in government and industry." Many others have also called for the improved communication of risks (e.g., Bell, 2007; Gill, 2007; Lindell & Perry, 2004; Mulilis, 1998).

Inasmuch as psychological studies show that people process information through existing knowledge, experts should exploit that insight in risk communication. Morgan (1993) suggests that the only way to convey risk appropriately is first to find out what people already know, then develop warning messages based on that information, and finally, evaluate the extent to which the communication was successful. More recently, however, others have worked on integrating scientific understanding of risk with political realities and even conventional wisdom. In this regard, Lane and colleagues (2011, p. 32) undertook an experiment looking at flood risk and showed a "deep qualitative understanding of flood hydrology, one that was not simply 'local,' and which through working with the event could be harnessed to produce and to negotiate a new and collective sense of knowledge." A collective sense of knowledge, therefore, was seen as a better approach to risk communication. Another study, undertaken by Bell and Tobin (2007), looked at how flood risk might be more effectively communicated in the United States, where the 100-year floodplain is used in policymaking. The problem arises from the generally misunderstood concept of a 100-year flood (or any event). They suggested that the terminology leads to confusion because the term conveys the misimpression that such events occur 100 years apart. Others have employed graphic models to communicate risk. Ash, Schuman, and Bowser (2014) evaluated the effect of different color and graphic schemes on understanding tornado risk in the United States and Europe. Fuchs, Spachinger, Dorner, Rochman, and Serrhini (2009) looked at the eye movements of respondents in attempting to determine which maps might convey flood risk most effectively. While the findings from these various studies have yet to be adopted, it is through such work that greater understanding of hazards and risks might be accomplished and communicated.

"Unconventional predictions" of disasters can also lead to misunderstandings, and experts need to respond appropriately and communicate risk when such situations arise (Showalter, 1994). As described in Chapter 3, a classic case of this kind garnered headlines when Iben Browning, who was not a seismologist, predicted that an earthquake would occur on December 3, 1990, near New Madrid, Missouri. Because this had been the site of one of the largest earthquakes in the contiguous United States, Browning's prediction aroused some fears, and a number of people reacted to his warning despite its lack of scientific underpinnings. The relevant authorities should always prepare for unconventional predictions by planning how to communicate accurate risk information based on scientific probabilities and the potential for occurrence.

For their part, the media also create problems. Journalists may have a limited understanding of risk and probability, which makes their reporting prone to error. Ben Goldacre of *The Guardian* newspaper in the United Kingdom has been particularly critical of the bad science represented in the media (Goldacre, 2011). The focus on sensational occurrences that in reality present very low risks to the general public tend also to lead to inaccurate perceptions of probabilities and likely outcomes. Indeed, the attention devoted to events by the media often bears little relationship to their actual severity (Adams, 1986; Combs & Slovic, 1979). There is evidence that the "media hype" associated with Hurricane Irene in the U.S. Northeast in 2011 may have contributed to a sense of complacency when Superstorm Sandy approached the same area in 2012, with disastrous consequences for many. Simon (2007) suggests that such imagery put forward by the media can often have profound negative effects on society at large. In a case study following the ravages of Hurricane Katrina in New Orleans, he found there were legitimate concerns over enduring memories stemming from the disaster. In essence, he stated that the harsh criticism of FEMA might lead to mistrust in government relief; community solidarity might be undercut by continuing memories of the chaos; and racial fears might be falsely engendered through an unfortunate combination of poor risk appreciation and inadequate coverage of the real events as they occurred. Simon (2007, p. i) described these images' potential impact on our awareness of risk in this way:

> For a long time American personal and governmental attitudes toward risk were shaped by the work accident as a model of modern risk and insurance as an exemplary tool of risk governance. In recent decades, those models and the images, narratives, and discourses supporting them, have been replaced by ominous images of grave technological disasters and fearsome violent crimes. These new figures haunting our risk imaginary have undercut support for broad measures of social risk spreading and encouraged privatization, isolation, and heavy reliance on police and prisons as tools of government. Now, the false memory of post-Katrina violence may reinforce those tendencies by condensing the disaster and crime fears of recent decades into a memorable and racially coded image of terror.

Undoubtedly, a large part of the risk communication problem may be attributed to the uncertainty that surrounds both expert and lay knowledge of risk. Scientific knowledge of probabilities of occurrence, available choices, and possible outcomes is lacking. Although there is a demonstrable need for clear communicaton of risk, there are many difficulties to achieve that objective.

Risk Analysis: Different Views Yield Different Decisions

Having a working definition of risk is a start, but we cannot stop there. Even more problematic than establishing a logical or functional relationship among variables is properly analyzing the results. Once a numeric or nonnumeric value for risk has been determined, the complex task remains of analyzing what it means to those affected or to other decision makers. One of the key issues in understanding risk and accomplishing risk assessment is the differing views people hold on the importance of various risks, which is discussed in some detail later in this chapter when different types of risk are considered. Here, it suffices to say that, regardless of individuals' experiences and training, it is not the scientific definition of risk on which they base decisions about which actions to take or to which hazards they will knowingly expose themselves. Thus far, the standard risk analysis paradigm—in which one chooses from among alternatives that have different potential outcomes, the probability of which can be measured—has not proven entirely satisfactory in explaining behavior.

Green and colleagues (1991) explored the differing views of risk held by engineers, emergency planners, and the public. While engineers tend to view risk as a measure of the probability of an event's occurrence, emergency planners tend to focus on the risks of miscommunication of (or listeners' apathy toward) official warnings (e.g., not heeding evacuation warnings or misunderstanding sheltering instructions). In contrast, views of risk held by the public are much more difficult to categorize because they vary based on individuals' experiences, among other factors. Even within groups, views of risk can vary, as found by an analysis of the use of weather forecasts by water managers (O'Connor, Yarnal, Dow, Jocoy, & Carbone, 2005). Those who felt at risk to problems created by weather events were more likely to use forecasts. These differences, both between and within groups, affect the relative success of risk communication as well. Each of us bases our decisions on our own assessment of risk. While perhaps starting from the same point, in this case the calculated risk value, we conclude or make decisions at different points in time as well as in other contexts. Knowledge is important, but only as part of the process. If risk involves choosing among actions and outcomes, each of the alternatives presented has characteristics that also influence views of risk. It may well be that differing views of risk relate to different levels of importance accorded to one or another of its components. For instance, some experts may evaluate risk by focusing on choices, with particular values attached to those choices. Others, perhaps laypersons, may focus on outcomes, particularly the manageability of outcomes (Smith, 1996). Thus, it is not merely differences in types and levels of risk that explain differences in attitudes and decisions. One also must look to the importance given the components of risk by the various decision makers.

Take, for instance, the influence of religion on risk decision making. Many individuals are bound by certain cultural and religious beliefs, and they respond to risks accordingly. We are familiar with risk taking by Christian Scientists, who consciously reject medical support and intervention in favor of prayer alone—a course of action that, to the outside observer, may appear to be counterintuitive and even thoroughly irrational, but that to the Christian Scientist is perfectly rational. Furthermore, religious adherents may view natural events as divine acts and believe that little can be done to prevent them. In some traditions, for example (as discussed in Chapter 4), deaths from disasters are attributed to wrongdoing, such as immoral lifestyles or irreligious behavior. It is not unusual for disasters to be interpreted by some faiths as manifesting divine wrath; the Lisbon earthquake of 1755 was followed by just such claims, as were the 1906 San Francisco earthquake, the 1993 floods in the upper midwestern United States, the California earthquakes of 1994, and Hurricane Katrina in 2005. Alternatively, some disasters are viewed as God testing the population at large rather than as divine punishment of individuals (Chester et al., 2012). At the same time, as Gaillard and Texier (2010, p. 82) note, "People do not assess risk in simple terms, in terms of either the threat of hazard or religious and cultural filters. . . . For instance the response of Javanese communities in facing eruptions of Mt Merapi is shaped both by syncretic religious beliefs and by a rational evaluation of the risks to livelihoods in the event of an evacuation."

In addition, in a South Carolina case study Mitchell (2000) found no impact of differing biblical traditions on the risk perceptions of Christian clergy. The relationship between death and religion is multifaceted (Spilka, 1985) and the extent to which it affects risk taking and decision making in hazardous situations is intriguing and has not been fully explored. It is in this realm that we recognize the role of cognitive dissonance—the ability to hold contrasting views and yet function in a somewhat (internally) rational way (as discussed in Chapter 4).

Measures of Risk

The first step in interpreting the extent and significance of differences in risk requires that we exercise greater precision in defining the terms we use. When people talk about risk, they are often referring to different things. There also are several common measures of risk (Starr, Rudman, & Whipple, 1976), which are frequently used interchangeably. The different measures include real, statistical, predicted, and perceived risk. Real risk is perhaps the most difficult to determine because of the role played by time; that is, real risk is determined by future circumstances as well as the history of actual occurrences. Statistical and predicted risk are "objective" estimates based on observed frequencies and theoretical probabilities, respectively (as discussed in Chapter 3). The former, which has been embraced by the insurance industry, is grounded in the scientific method and uses common statistical techniques. In contrast, where there is a lack of experience with or knowledge of frequencies and outcomes, predicted risk relies on simulation models. It is used most often for events that have an extremely low probability of occurrence, where the historical record is incomplete.

Our primary concern here lies with perceived risk, or the subjective value to which people react and respond. Research on risk perception shows that scientifically based quantitative measures are generally less important than the qualitative attributes of a risk—and are definitely more complex than those measures based on simple psychological types (Allison, 2015). People tend to evaluate risks in a multidimensional but subjective manner, and as a result some risks become "socially amplified" and others "socially attenuated" (Kasperson, 2015; Kasperson et al., 1988). In other words, some risks may be perceived as greater than scientific measures would suggest—that is, they are overestimated—because their effects are judged to be unacceptable, whether socially, economically, psychologically, or otherwise. For example, after the nuclear power plant accident at Three Mile Island, similar plants around the world were shut down, checked for safety, and restarted more frequently than prior to the accident—despite this procedure's being among the most risky of normal operations. Similarly, the Japanese earthquake and tsunami in March 2011 compromised the Fukushima nuclear power plant so much so that it has since been closed—while other power plants were immediately taken off line, at least temporarily, as a safety measure. This latter response is understandable, given the significant consequences of failure, but from a risk perspective it is not necessarily sound (Cyranoski, 2007). Other risks may be underestimated or attenuated and thus receive less public concern and attention than they deserve; examples would include raised speed limits, which inevitably entail additional lost lives, and, until the late 20th century, cigarette smoking.

Many factors contribute to risk perception, including exposure, familiarity, preventability, and dread (Coburn, Spence, & Pomonis, 1991). Again, the different weightings associated with these factors illustrate the divergence between lay and expert estimates of risk. These differences are frequently evident in estimates of the risks associated with land uses proposed for particular places, especially noxious or unwanted facilities such as landfills, solid waste incinerators, and jails. Expert estimates frequently ignore the social and cultural context within which risks are evaluated by the public and misconstrue the role of individual and group perceptions.

As discussed in Chapter 4, perception is a complex concept that provides a basis for understanding responses to risks and hazards. While perceptions are difficult to measure precisely, which frustrates many experts in risk analysis, there are social, cultural, and psychological components to laypersons' estimations that go a long way toward explaining why some risks are judged to be acceptable and others unacceptable or why some risks are socially amplified and others attenuated. Acceptable risk is not different from perceived risk, although acceptable risk depends on the perception of both risks and benefits—that is, risks, benefits, and costs must all be understood fully before a risk can be properly judged as either acceptable or unacceptable. Furthermore, risk perception is a dynamic process, and new choices or information about outcomes constantly lead to new perceptions.

Perceived Risk

Within the large body of research on risk, much attention has been given to determining and weighing the factors that affect risk perceptions (Sjoberg, 2000). This is an enormous challenge because of the range of social, psychological, physical, technological, and cultural factors involved and the interactions among them. For example, Slovic (1987) showed that the perceived risk of 30 different activities and technologies varied significantly among social groups; college students and members of the League of Women Voters ranked nuclear power as the most risky, whereas experts ranked motor vehicles as entailing the highest risk and nuclear power only 20th. Risk, then, means different things to different people, and the importance of understanding risk perception and the factors contributing to it cannot be overstated. If we do not understand risk perception, we can neither comprehend nor anticipate responses to risk, which complicates any risk reduction strategies.

Determining which social, psychological, and environmental factors influence risk perception is not easy, and a number of techniques have been used to discriminate among them, including social and attitudinal surveys, usually based on individual questionnaires, and various scales based on psychometric analysis and multidimensional scaling. (Applications of scaling methods are discussed in Ajzen & Fishbein, 1980; Slovic, Fischhoff, & Lichtenstein, 1985; Tversky & Kahneman, 1982.) Each of these techniques has been criticized (for examples, see Allison, 2015; Sjoberg, Moen, & Dundmo, 2004) either methodologically or in specific applications. Although we should interpret the results with caution, the data are enlightening and, on the whole, allow for evaluation of the complexity of factors involved.

Table 8.1 categorizes the factors affecting risk perceptions, based on the nature of the risk, the nature of its consequences, and individual or social characteristics. The three categories show that the characteristics of a risky activity and its consequences are critical to one's perception. Individual characteristics might be seen as

TABLE 8.1. Some Factors Affecting Risk Perception

Nature of the risk	Nature of the consequences	Individual/social characteristics
• Voluntary or involuntary • Known to science • Measure of control over the risk (controllability) • Changing character of the risk • Availability of alternatives • Necessity of exposure • Possibility for misuse	• Immediate or delayed • Chronic, cumulative, or catastrophic effects • Common or feared consequences • Severity of consequences • Size of group exposed • Distribution (equity) of exposure • Effect on future generations • Global catastrophic nature • Average number of people affected • Reversibility of the consequences	• Familiarity with the risk • New risk or an experienced risk • Degree of personal exposure • Perceived ease of reducing the risk • Occupational hazard

Note. Data from Slovic, Fischhoff, and Lichtenstein (1979); Covello, Flamm, Rodricks, and Tardiff (1981); and Griffiths (1981).

an overriding layer against which factors associated with the risk and consequences interact. This typology is not entirely neat, as some factors fit into more than one category, but the various groups differentiate factors in ways that are meaningful for analysis and discussion. Nevertheless, the reader should not necessarily assume that these are discrete factors that are individually relevant in every situation. They are not independent but rather interact with a number of other factors to shape perception. Different combinations of the same factors can result in different, yet perfectly rational, decision making, and not all factors will apply in all circumstances (Fischhoff, Slovic, Lichtenstein, Reed, & Coombs, 1978; Starr, 1969).

In addition, other socioeconomic and situational traits must be considered when addressing perceived risk, including age, income, education, and gender, each of which have been found to influence perception almost irrespective of the factors on the list in Table 8.1. However, research results are usually mixed. Arlikatti and colleagues (2006), for instance, found that demographic factors had little bearing on awareness of hurricane risk zones and no impact on decisions to evacuate in the event of a disaster. In this study, personal experience of disasters was more important. In contrast, Zhang and colleagues (2004) found that higher incomes and longer tenure in the hazard area correlated with greater accuracy in awareness of the risk area. Other researchers have highlighted the importance of cultural identity in influencing one's perceptions of risk, with Johnson (2004), for example, arguing that ethnic identity and acculturation may play key roles in risk awareness.

Another theme of risk applies not to the individual per se, but rather to the collective. It is likely, for instance, that social networks have a greater influence on perceived risk than do individual traits (Scherer & Cho, 2003), as "risk levels" readily become memes within society. Gruev-Vintila and Rouquette (2007) argue that collective risk, termed *socio-environmental phenomena*, needs to be addressed if positive behavioral outcomes are to be expected. They state that "if collective conduct is sought in relation to a risk, the strategy consisting solely in increasing interest in (or fear of) that risk is probably a quite ineffective one, but the strategy that increases individuals' involvement in risk after having provided them with sufficient practical training should be an effective one" (p. 572). Similarly, noting that effective communication is important, Lindell and Perry (2004) stressed the need for consideration of possibly different risk communication strategies for multiethnic communities.

What is unclear, however, is how these various influences, individual perceptions, and collective risk awareness work together and/or separately to fine-tune perceptions of disaster risk. As discussed in Chapter 4, these additional variables influence perceptions of hazards, but it is important to consider the related and yet not identical perceptions of risk. In particular, we are concerned with perceptions of risk probabilities and outcomes, as these stem from the characteristics of the intrusion, while aspects of personal vulnerability come into play later.

The nature of the risk has been found to have an important influence on perception, though there is some discrepancy in the results of various studies. For instance, Starr (1969) indicated that perception and acceptability of risk are influenced by whether the activity that includes risk is voluntary. While Slovic, Fischoff, and Lichtenstein (1979) could not correlate perceived with voluntary risk for more than 30 hazards, there is some evidence that the extent to which people face risks voluntarily is salient to perception (Slovic, Fischoff, & Lichtenstein, 1980). This relationship is complicated because some risks may appear to be voluntary, such as locating in a flood-prone area, when in fact the individuals concerned may have few options because economic constraints may predetermine their available choices. Therefore, consideration also might be given to questions of fair and unfair risks, although there are difficulties in drawing such general distinctions because of the context in which risk taking occurs (Sagoff, 1992). Heath and McComas (2015) go further and stress the need for considering fairness in risk evaluation as well as the need to consider different interests, ultimately posing the question "How fair is 'safe'?" In other words, could we consider the risk of tornadoes to be fair because they can occur virtually anywhere, while living in squatter settlements on unstable slopes might be considered unfair? The categorical distinction for tornadoes, too, blurs when the effect of housing structure on tornado damage is added.

These issues illustrate the complexity of risk perception as well as the differential influences that various factors can have. Take, for example, acute and chronic (or intensive and pervasive) hazards and their impact on risk perceptions. In a comparison of individuals located near an active volcano and those living in landslide-prone areas in Mexico, it was found that such chronic hazard conditions elicited higher levels of awareness of risk (Tobin et al., 2011). In light of the many possible combinations of variables given in Table 8.1, the search for order in perceived risk is indeed an onerous task. At the same time, risk is not static. It changes as we learn more about it; as alternative activities or mitigation strategies are developed, and as the physical environment changes, so risk perception changes constantly along with those factors. Evacuees from Hurricanes Katrina and Rita in the United States, for example, subsequently perceived risks from hurricanes to be far higher than the geophysical data would suggest, and consequently will not likely return to New Orleans (Baker, Shaw, Bell, et al., 2009). Another study suggests that individuals have difficulty processing information, such as educational materials on risk, after a major event like Hurricane Katrina, and perceptions of risk remain subjectively high (Baker, Shaw, Riddel, & Woodward, 2009). Brommer and Senkbeil (2010) interviewed residents in the path of Hurricane Gustav about their perceived risks prior to landfall to determine what led to their decisions to evacuate. The results showed that perceptions of risk varied by location along the coast, although the threat posed by storm surges was predominantly evident in New Orleans itself. Again, the nature of the risk may be affecting perceptions because the negative memories of Hurricanes Katrina and Rita were then still prevalent. Over time, of course, these perceptions will modify.

Nevertheless, we cannot focus solely on the nature of the risk. Risk perception is also influenced by the perceived consequences of a particular activity or location, since risks differ in severity and the probability of consequences. Perceived outcomes such as the immediacy of a threat, dread associated with the risk, number of people likely to be affected, and the potential for catastrophe all greatly influence risk perception. Consequently, individual perception of risk rarely corresponds completely with technical risk. An individual's "misperceptions" may be chiefly related to fear of consequences rather than probabilities of occurrence. For instance, many people express great fear of flying but are relatively unconcerned about driving to and from an airport—although statistically, of course, the latter is far riskier than the former; similar patterns emerge with natural hazards. In addition, familiarity and denial play important roles in risk perception; there is reassurance in the perception that others are probably worse off because the others face greater hazards. For example, Californians might express surprise that midwesterners can live with tornadoes occasionally cutting wide swaths of devastation through their communities, while midwesterners conversely might have trouble comprehending how Californians can live where earthquakes level their living or working quarters. Obviously, many more variables influence perception than are discussed here.

To some extent, the popular media also affect perceptions by highlighting risks and fatal incidents. The resulting image of risk encourages the perception that every element of life, especially in "other people's environments," is extremely hazardous. Again, these relationships do not work independently or consistently; their effects vary from risk to risk, from person to person, from place to place, and from time to time. For example, Lave and Lave (1991) have found that public perceptions of flood risks are skewed in certain respects because of inadequate communication, specifically suggesting that current government publications are not likely to be understood by those at risk. They found that people who worked and had higher levels of education knew more about flooding and were more likely to have flood insurance than the less well-educated respondents.

Our studies, then, have identified several systematic biases in laypersons' risk perceptions. These include the memorability or imaginability of a hazard (related to an availability heuristic, discussed below), overconfidence in their risk judgments, and tendencies toward underestimating uncertainties (Tversky & Kahnemann, 1982). Combined with other factors, these biases contribute to the acceptance of certain risks while others are deemed unacceptable, and the findings provide ample evidence of the complexities of understanding risk. Thus, one question to which risk analysts have returned repeatedly is: How safe is "safe enough"?

Accepted and Acceptable Risks

A distinction must be made between accepted and acceptable risks. Some risks are viewed as the consequence of living in a particular location, and while these may be an accepted part of a given lifestyle, that does not necessarily mean that they are acceptable to the wider community (or society) at large. For example, Bangladeshis may accept the hazardousness of their existence without feeling that the risks are acceptable. Even those who choose to live in hazardous locations, such as on unstable slopes or eroding cliffs, may come to accept the risk but still consider it "unacceptable." In fact, we face risks every day and accept the attendant outcomes—but that does not necessarily make them "acceptable." When one's choice is limited, the balance of perceived risks and benefits is severely constrained, but it still can be argued that the risk is accepted.

By contrast, acceptable risk is determined by the decision-making process. Benefits, perhaps of increased safety, are balanced against the costs of reducing risk or restricting hazardous activity (Fischhoff, Lichtenstein, Slovic, Derby, & Keeney, 1981; Fischhoff et al., 1978). Thus, acceptable risk is based on perceived risks and benefits, particularly perceived benefits. However, there are problems with this definition of acceptable risk. For instance, once the term has been applied, it may wrongly imply that a risk is acceptable to everyone. In fact, the distribution of risks and benefits can be quite inequitable (see Chapter 7). For example, charges of environmental racism are based on the inequitable distribution of risks (Walker & Burningham, 2011). We must therefore consider to whom a risk is acceptable and evaluate the social, political, and economic contexts in which risk is decided to be acceptable. It may be that a risk only appears to be acceptable when instead it is merely accepted, necessary, tolerable, or unknown.

Necessary risks exemplify accepted risks that, in a different context, may not be acceptable. Necessary risks are those we face unavoidably—for instance, as a result of our occupation, income, or age—and their outcomes are not changed easily through our own volition. Some necessary risks exist because political decision makers have determined that they are necessary to attain socially desirable objectives. An example of a necessary risk might be floodproofing public buildings rather than moving them off the floodplain. Although floodproofing allows buildings to remain centrally located, the workers and visitors are still vulnerable. The workers take a necessary risk, which they accept for their employment's sake, but that does not necessarily make the risk truly acceptable.

Tolerable risk represents temporarily acceptable risk. An individual may be prepared to tolerate a risk because it is confined to a brief time period or is associated with a short-term activity. For example, those living in the northern states of the United States tolerate extreme wind chill, knowing that it is seasonal. Individuals who venture outside to record tornadoes could be described as treating that activity as a tolerable risk, with benefits accruing from the resulting photographs.

It has been argued that risks fall along a spectrum of accepted through acceptable (Dinman, 1980), but there are also risks about which we currently know very little or nothing. As we come to learn more about hazard magnitudes and probabilities, it may appear that these risks were accepted, if not acceptable, when in fact they were unknown. This possibility illustrates the need for dynamic risk analysis because, at different times, risks may be (variously) accepted, acceptable, necessary, or tolerable.

Some attempts to measure accepted and acceptable risks have focused on economics, especially such principles as the willingness to pay and revealed preferences. It has been argued that societies arrive at "optimum solutions" to hazard risks (Slovic, 1987) through a process of evolved tolerance (Alexander, 1993). In other words, the existing conditions for a particular community may reflect the currently accepted level of risk. If society is willing to pay for reduced risk through the construction of a mitigation project, then that provides evidence of acceptance. The actual accepted risk level may be reached through trial and error as conditions and attitudes change and as different projects are implemented. The strengthening of building codes in earthquake areas is an example of this trial-and-error search for an acceptable level of risk.

While the actions of society may reveal much about communal attitudes toward risk, they do not necessarily reveal an optimal solution. Sagoff (1992) argues against the concept of revealed preference (discussed in Chapter 4), contending that past actions are simply those that have occurred. For example, in 18th-century mills in England, intolerable working conditions were accepted by workers who had little choice. Those conditions did not result from societal decision making, but rather from a few mill owners who dominated the decision-making process. Similarly, people living in hazardous environments, such as the squatter residents of urban agglomerations, may not willingly accept the risk, but they have little alternative but to tolerate their situation. Their powerlessness contributes substantially to their vulnerability.

There also appear to be different acceptance levels for voluntary and involuntary risks. Generally, people are more willing to accept higher risks from voluntary actions than from involuntary ones. Starr (1969) reported that, given similar types of benefits, the accepted levels of risk were a thousand times higher for voluntary activities. While there are criticisms of his study, its findings echo a common theme, namely, that people tend to be more tolerant of risks borne by others and less tolerant of those borne by themselves. For example, it is estimated that in the United States some 480,000 people die annually because of smoking and second-hand smoke, and yet this was considered socially acceptable until late in the 20th century (Centers for Disease Control and Prevention, 2014; Dinman, 1980). Similarly, in 1996, many states raised speed limits on certain roads, demonstrating a willingness to tolerate more traffic deaths as a direct consequence. In contrast, consistent action has been taken to minimize deaths from traffic accidents by passing laws requiring seat belts, which are credited with saving up to 20,000 lives per year.

The most obvious question is: Where does society draw the line? Although most laypersons find most risks unacceptably high, individuals continue to participate in hazardous activities (Slovic, 1987). However, attitudes are always changing (Morgan, 1993). We have seen increased seat belt use and airbags in cars, reduced smoking, and improved diets that have reduced many risks. On the other hand, despite laments from industry lobbyists claiming dire economic and workforce consequences from the initiatives above as well as stepped-up Environmental Protection Agency (EPA) regulation aimed at cleaner air, these are relatively inexpensive measures to implement and may not be comparable to large-scale mitigation projects aimed at reducing natural disasters. The relative willingness of society to pay for reduced risk remains a useful measure of accepted risk.

Availability of Information and the Role of the Media

An important factor that greatly influences perceptions of risk is the accessibility of information, termed the *availability heuristic* (Tversky & Kahnemann, 1982). Although it is not listed separately in Table 8.1, it is an important component of several factors such as familiarity with a risk and the average number of people affected. This heuristic suggests that events are judged to be likely or frequent if they are easy to recall. In other words, the more available the information concerning the occurrence of an event, the more likely it is that people will expect the event to recur. Personal experience with disasters, especially with more than one event, may translate into more accurate perceptions of risk, but because many natural hazards have a low probability of occurrence. With larger-magnitude events occurring with much less frequency, most people do not have this reinforcement from personal experience. Consequently, their information is obtained from the media, which influence risk perception through the reporting, or nonreporting, of events, which brings us back to the amplification of risk and the ripple effect this can have, as described by Kasperson (2015).

Studies of media reporting have found an emphasis on life-threatening events, which are not closely related to statistical frequencies (Combs & Slovic, 1979); catastrophic events such as tornadoes, homicides, and fires tended to be reported disproportionally often. Thus, the information that is easily available and accessible to laypersons often gives an inaccurate and distorted view of risk, particularly when the context in which the events take place is not considered (Rashid, 2011). It is little wonder that perceived risk can differ so much from real or statistical risk. The media, however, are only one influence on perception, albeit a very important one. Other studies have shown that people are reasonably accurate when asked to rank-order a number of common or well-known hazards based on injuries and deaths, but when asked to rank them in terms of risk, the results are much less accurate (Morgan, 1993).

SUMMARY

Risk is more than the simple probability of an event, though that often is how it is measured. Any analysis of risk must include vulnerability, including absolute and relative measures of the population and property at risk. Even when we include these variables, however, there is difficulty in managing risk. One might assume that once risk is defined and measured, appropriate steps to minimize it can and will be taken, but that depends on the nature of the risk and the decisions to be made. Of course, decision makers—whether public or private, individuals or groups, experts or laypersons—approach the problem with different experiences, fewer or greater constraints on choice, and perhaps even different views of what is meant by risk. Furthermore, risk is dynamic. All these factors influence the ability to manage a given risk, assuming we even have the opportunity to do so. As a critical component of any comprehensive analysis, risk confounds, but does not entirely diminish, our capacity to address natural hazards.

The Changing Nature of Risk

As we have seen, risk is not only measured in different ways, it is also perceived differently. Thus, it is an elusive concept, particularly as it relates to natural hazards, which presents an ever-changing and challenging environment. Global climate change, for instance, is particularly problematic. We know that the climate is warming overall, but the pace and precise impacts on weather remain uncertain. How weather changes will affect the potential for disasters at specific locations is even less well defined (Intergovernmental Panel on Climate Change, 2007, 2012). In our attempts to understand risk, therefore, climate change merely adds to the uncertainties and has led to "heated debate" (Simon, 2012). It is easier to predict slow-onset events such as sea level rise, although that in itself does not guarantee a positive (political) response. How climate change affects other weather events such as hurricanes and tornadoes is less clear. In addition, population growth, urbanization, and economic globalization have all modified risk in one direction or another. Gardner (2015), for example, discusses how evolving conditions in mountainous areas relating to expanding development and increasingly diversified economies have increased the complexity of risk through globalization, thus rendering local development dependent on distant markets and intensifying ecological damages resulting from increased resource extraction.

Risks from Nature and Risks from Technology

The risks associated with natural and technological hazards are often discussed interchangeably. Indeed, when exploring risk as a concept, to some extent it matters very little which type of hazard is being considered. Early on in this volume, we cited the different levels of risk (expressed as the probability of death) associated with various health, technological, and natural hazards (see Table 1.4). The data show that the risks of dying from various natural hazards are not particularly different from those associated with other hazards or diseases. However, much of the research on risk and hazards has dealt with technological rather than natural hazards, and as a consequence natural hazards research often has borrowed concepts or adapted insights from that related literature.

To a large extent, that is a reasonable practice. Table 8.2 illustrates the similar grounds on which risks from both types of hazards can be measured, and while the terminology is slightly different, the variables are essentially the same. For example, the greater the quantity of a pollutant or chemical released, the greater the risk in most cases—likewise, in the natural hazards realm, the greater the physical magnitude of events, the greater the risk. This is not to say that the nature of the risk is not important. For instance, the level of uncertainty associated with each common variable differs among hazard types, and the physical characteristics of the risk source can have a distinct influence on the perceptions, acceptance, and management of risk. Because natural and technological hazards differ in many respects, however, we can expect differences in the composition of the risks and in risk perceptions. Our focus in this volume remains on natural hazards, with occasional references to technological hazards where appropriate.

Figure 8.4 compares the number of deaths worldwide from 2004 through 2013 attributable to natural and technological hazards. Although these data suggest that natural disasters cause much greater loss of life, for the most part natural hazards are not seen to be as great a risk as many technological hazards. Other comparisons lead to very different conclusions; for instance, many technological accidents surpass natural hazards or at least are comparable to major disasters in terms of resulting fatalities. For example, the 1984 industrial catastrophe in Bhopal, India, where a chemical release killed more than 2,500 people during the first few days and injured or disabled thousands more, far exceeds most natural hazards in its severity. Similarly, the failure of the nuclear power plant at Chernobyl in 1986 has had long-term catastrophic consequences for the local populations and the landscape. Another way of comparing these two categories of hazards is by cumulative deaths. Many more people die in automobile accidents in the United States than in all natural hazards there combined, but the fact that the deaths do not occur all at once alters our

TABLE 8.2. Variables in Risk Assessment

Technological hazards	Natural hazards
Probability of release of a harmful substance	Probability of occurrence
Quantity of a harmful substance released	Magnitude
Dispersion of the harmful substance and the resulting concentrations in the environment	Spatial extent
Population exposed to release of a harmful substance	Population in the risk area
Uptake of harmful substances by humans and other organisms	Occurrence of the geophysical event
Relationship between dose of the harmful substance and adverse toxicological effects	Vulnerability or damage potential
Measurement error	Measurement error

Note. Data from Talcott (1992).

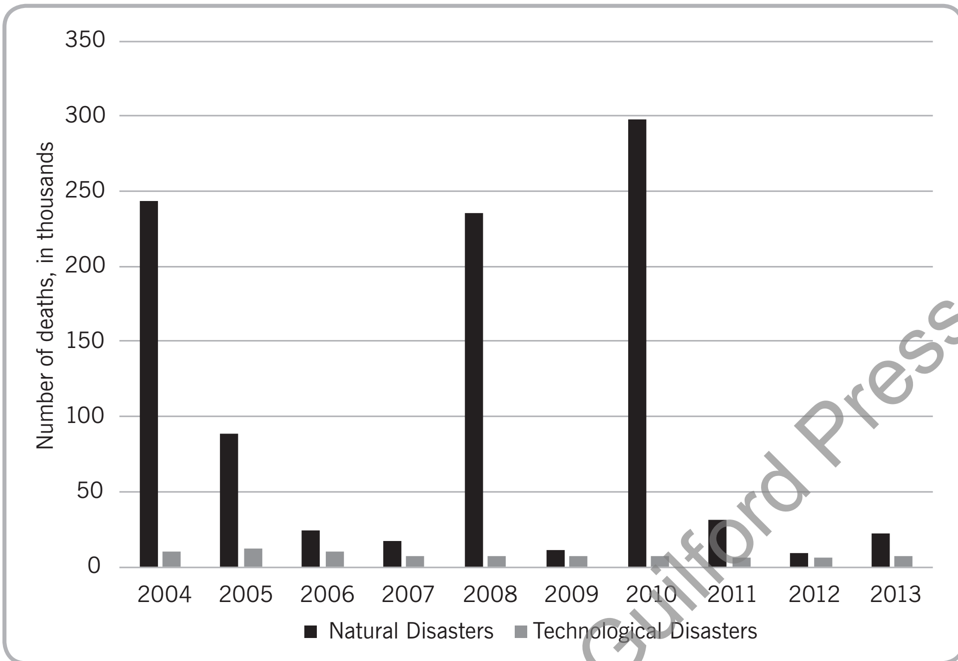

FIGURE 8.4. Comparison of natural and technological hazards. When considered on a similar scale, the former greatly exceed the latter in death tolls. From Centre for Research on the Epidemiology of Disasters (2015b).

perceptions of the risk. Indeed, it is instructive to think about the differences among hazards that lead to such varied perceptions.

Natural and technological hazards often influence each other. Indeed, "natural and technological hazards coexist and can combine synergistically" (Showalter & Myers, 1994, p. 181). Technological hazards have been known to cause certain natural events, including earthquakes in Saskatchewan brought on by underground mining and in Oklahoma caused by hydraulic fracturing (Holland, 2013; Stevens, 1988) as well as earthquakes caused by filling reservoirs (El-Sabh & Murty, 1988). Natural hazards, conversely, can likewise lead to technological failures, such as when an earthquake causes a dam to break, or floodwaters put fuel tanks at risk (Gruntfest & Pollack, 1994), or when a tsunami damaged a nuclear power plant in Japan (Dauer, Zanzonico, Tuttle, Quinn, & Strauss, 2011). The floods in Texas in October 1994 led to fuel leaks that ignited and spread fire along extensive reaches of the San Jacinto River; similarly, fires broke out in Grand Forks, North Dakota, during floods along the Red River of the North in 1997 (North Dakota State University, 2013; University of North Dakota, 2013).

It is the latter situation, where extreme geophysical events create technology-related crises/emergencies, or technological breakdown, that is of increasing concern to researchers, regulators, and emergency managers. These emergencies, termed *natech events,* present some real difficulties in preventive planning and management, largely because of the complexities of combined risk (Cruz, Kajitani, & Tatano, 2015). The threat of natech events varies from year to year, as illustrated in Figure 8.5 (for the period 1990–2003), but, as can be seen, the worldwide incidence is high. Older data from Showalter and Myers (1994) show that, for 20 U.S. states from 1980 through 1989, earthquakes were responsible for the majority of natech events though floods accounted for the most disasters (see Chapter 2). Nevertheless, such events as the 1993 floods in the Mississippi River system and Hurricane Katrina in 2005 certainly increased the visibility of natech events, with numerous accounts of threatened fuel tanks and chemical releases in the flood hazard areas and attempts by industry to mitigate the natech hazard (Gruntfest & Pollack, 1994; Steinberg, Sengul, & Cruz, 2008). Cruz and Okada (2008, p. 213) point out that regulations tend to require design standards for industrial structures to withstand disasters but that there are "few laws to address the performance of non-structural elements and safety and emergency response measures during a natural disaster." Certainly, the earthquake and tsunami in 2011 that devastated parts of Japan and compromised the Fukushima nuclear power plant has led to serious ongoing problems (Cyranoski, 2012).

We are dealing, then, with what might be considered a combination of risks. It is logical to consider the risk of each independently, but it also makes sense to consider

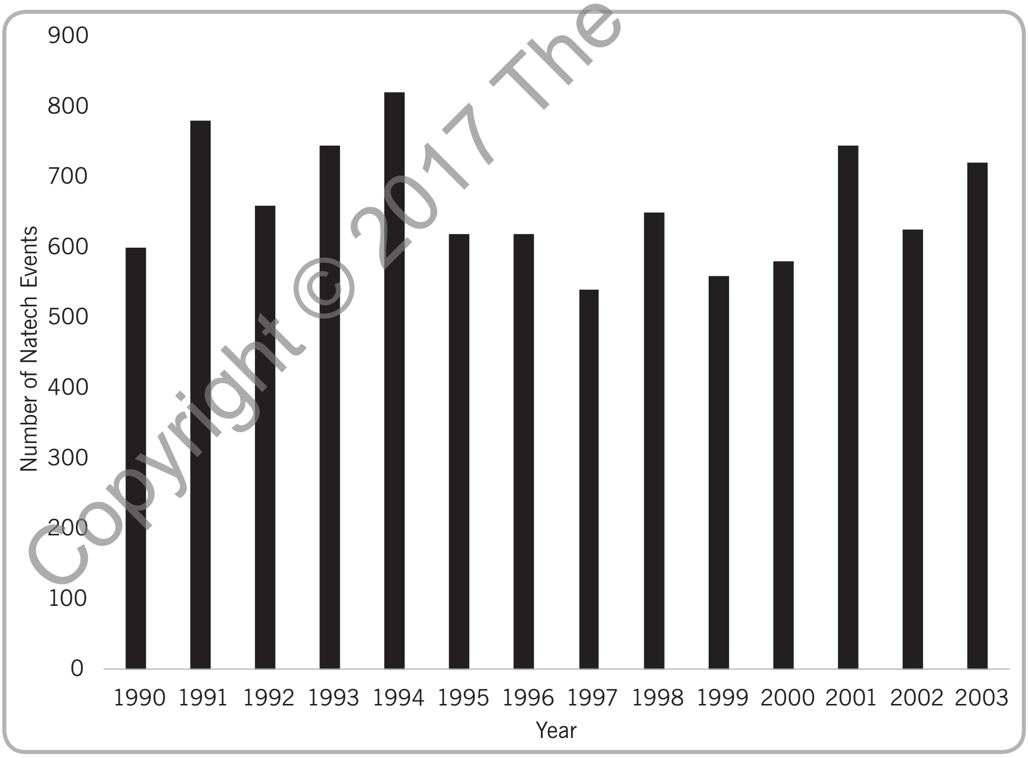

FIGURE 8.5. Natech incidents from 1990 through 2003. The largest number occurred in 1994, probably many resulting from the Northridge, California, earthquake. This is not surprising as earthquakes have been found to cause the greatest number of natech events. Data from Steinberg et al. (2008).

the risk resulting from their interaction, which becomes increasingly complex as the number of variables increases. This is difficult enough when considering the risk from multiple natural hazards at a location. Incorporating risk from technological hazards increases the complexity, perhaps disproportionately. With technological hazards, one must consider the risk of disaster resulting from technological failure or human error as well as such physical parameters as seismic fragility (i.e., the potential for, and effects of, failure of structures and equipment resulting from different intensities of ground motion) (Reiter, 1990). The risk is changed in terms of both probability of occurrence and consequences. During the Mississippi River floods of 1993, a propane tank in Jefferson City, Missouri, broke loose from its moorings, cracked open, and was carried along with the floodwaters. Had the fuel ignited, the consequences of flooding would have paled in comparison to those from the resulting explosion. Indeed, most floods can lead to damage to structures that set in motion potential problems with chemical and toxic spills (Montz & Tobin, 1998). However, the relationship between flooding and chemical spills can be difficult to assess, as studies following a flood in Idaho have shown. Despite the fact that pollutants were released, only selected metals could be detected in floodplain sediments once floodwaters receded (Brinkmann, Montz, & Tobin, 2000; Tobin, Brinkmann, & Montz, 2000). To what extent flooding dilutes and disperses chemicals or concentrates them requires further study. Of course, some of this risk can be mitigated, but that requires sufficient recognition of the combined risk to undertake preevent vulnerability analysis (Showalter & Myers, 1994; Steinberg et al., 2008).

Despite similarities, characteristics of the risks associated with these hazards differ. Generally, a technological hazard is "controllable" in that safeguards are normally incorporated into the technology and their failure is required for an event to occur. By contrast, natural hazards are not generally controllable, although loss from them may be. This difference impacts risk both statistically and, more importantly, perceptually. Mitigation measures for natural hazards are designed to lessen risk and vulnerability, perhaps by changing physical characteristics from uncontrollable to controllable. Such measures also change the risk from natural to technological—so that it is the failure of the technology rather than the natural system that causes an event. The sea wall designed to prevent damage from storm surges in the event of a hurricane offers protection from an event of a particular size, but when a larger event occurs the structure may fail, presenting a technological rather than natural problem. The situation is summed up by Cruz and colleagues (2015, p. 459) thusly: "Given the complex and interconnected nature of natechs, a more comprehensive risk governance framework is needed that brings together major players and stakeholders in order to adequately capture the full range of issues and alternative solutions."

Changing Risks by Mitigation

The implementation of hazard mitigation measures or projects affects all aspects of risk (Smith, 2013), whether actual, scientific, technical, or perceived. As noted in Chapter 4, mitigation projects frequently generate a false sense of security and reduce the perceived risk. Consider, for example, the variable nature of risks associated with earthquakes. The seismic hazard is determined by measuring the magnitude and intensity of earth movements, as manifested through attendant ground shaking, deformation, soil liquefaction, and landslides, with effects including property damage, injury, and death. The probability of negative consequences depends on the magnitude of the geophysical event and the preventative measures taken within the affected region (Reiter, 1990). Because an earthquake is uncontrollable, society must depend on adjustments to reduce the consequences, and those adjustments change both the perceived and actual risks even though the seismic processes remain constant. Thus, risk is reduced because vulnerability is altered, but the probability of occurrence of an event remains the same. The adoption of mitigation measures effectively lowers the risk, at least for earthquakes of a given magnitude, but if an earthquake exceeds the design standards, the measures may fail.

Floods provide another example. In the United States and elsewhere, engineered structures have been used historically as mitigation measures, providing a means of controlling the flow of rivers and therefore controlling the hazard (Tobin, 1995). This both lowers and changes the nature of the risk. Because of flood control measures like dams, levees, and floodwalls, the actual risk of flooding from small floods is diminished at a given place. However, the development of dams and levees also has created a technological hazard, with the risk of flooding being redirected to the risk of dam or levee failure. The problem is exacerbated by the false sense of security provided by flood control measures. This false sense of security might also be termed *residual risk*, that is, the level of risk remaining once mitigation strategies have been implemented (Montz & Tobin, 2008a; Sayers et al., 2013). Ultimately, some sense of responsibility must lie with the persons located in the disaster area.

It may be argued that the failure of a dam or levee is a natural disaster because the result is the same: destruction, property damage, injury, and perhaps loss of life. However, the nature of the flooding is different. Except with flash floods, natural floods are more likely to develop gradually, allowing time for warning and evacuation. With technological failure, however, flood heights and the velocity of flood waters often can be increased, leaving less time for warning and evacuation and resulting in greater losses. Risks may well be underestimated if the probability and consequences of technological failure are not considered.

Risks from Multiple Natural Hazards

In 1997, FEMA published a somewhat misnamed book titled *Multihazard Identification and Risk Assessment: A Cornerstone of the National Mitigation Strategy.* The agency's intention was sound—to determine the overall hazardousness of places all over the country. However, lacking from this directive was a truly integrative methodology for estimating risk, since the study essentially invoked the traditional approach of breaking down hazards by specific hazard type. In fact, most places are subject to more than one natural hazard. For instance, many parts of California are subject to earthquakes, floods, drought, landslides, and wildfire; Bangladeshis experience hurricanes, riverine flooding, storm damage, and occasional tornadoes; and many countries in western Europe are exposed to blizzards, flooding, drought, and earthquakes. Thus, while multihazard risk assessment definitely appears to be needed and more research is being devoted to such assessments, unfortunately this approach is rarely adopted in assessing hazardousness or riskiness. Instead, the focus has been on the risk posed by single hazards, which does not provide a sufficiently comprehensive understanding of the overall risk that exists at any given place. This can lead to gross underestimates of risk and hazardousness, which in turn results in inadequate risk management.

The classic work on multiple hazards at a single place was undertaken by Hewitt and Burton (1971) in a study of London, Ontario. Although considered by the authors at the time to be an exploratory effort, this research remains relevant today. Hewitt and Burton examined the joint-risk magnitude for all hazards, which they suggested would provide the integrated view of vulnerability needed for planning purposes. Furthermore, they considered the cumulative effects of smaller hazards, which frequently are thought to pose only small risks. The authors provided a valuable analytical framework for the interaction of various components of the physical and human systems that inspired further studies. For instance, in Rotorua, New Zealand, their framework has been adapted for a planning context, as shown in Table 8.3 (Montz, 1994). A number of factors contribute to multiple hazard risk, some related to the nature of the geophysical events (such as the probabilities of occurrence) and others to the probable magnitude of the consequences (such as the spatial extent of the impact).

TABLE 8.3. Comparison of Hazard Characteristics in Rotorua, New Zealand

Hazard	Probability		Spatial dimensions			Onset intensity[b]	Forecast/ warning abilities
	Known or calculable	Independent/ dependent	Known	Variable within city	Widespread/ limited[a]		
Earthquakes	Modified Mercalli recurrence intervals	I, D	Y?	N/Y[c]	W	Very high	None
Volcanic activity	Y	I	Y	N[d]	W	High–moderate	Moderate–none
Geothermal activity	Return periods	I, D	Y	Y	L	Very high–high	None–moderate
Subsidence	N	I, D	N[e]	Y	L	High	None–moderate
Hydrogen sulfide gas	N	I	Y	Y	L	Moderate–high	Poor–moderate
Seiches	N[f]	D	Y	Y	L	Moderate–high	None
Stream flooding	Y	I	Y	Y	L	Moderate	Poor–moderate

Note. Adapted from Montz (1994).
[a]Extent or size of the area likely to be affected by an event.
[b]After Hewitt and Burton (1971).
[c]Depends on location of movement and magnitude of event.
[d]Except perhaps the depth of tephra.
[e]Except relating to geothermal activity.
[f]Models for determining amplitude under various conditions exist but have not been widely applied.

The picture is complicated, however, as shown by Glavovic, Saunders, and Becker (2001) in relation to land use planning and mitigating disaster risk. They pointed out that certain reforms in hazard planning held much promise, the chief intention (or promise) being that the central government would support local communities whenever events exceeded the localities' capacities to cope. As the researchers ended up having to admit, however, "This promise has not been realised fully due to shortcomings in governance, and inter-governmental cooperation in particular. Central government needs to assume a more effective role in enabling local government and communities to reduce hazard risks and build resilience" (p. 702).

These studies illustrate some of the challenges associated with trying to evaluate the collective risk from multiple hazards at a single place. First, as pointed out by Hewitt and Burton (1971), the data on hazard characteristics are often grossly inadequate and present problems in comparing different geophysical events. Second, there is a distinct paucity of satisfactory analytical models, which compromises risk assessment. Although progress has been made in both of these areas since 1971, contemporary research on multiple hazards remains somewhat limited. Third, the differences between natural hazards are not always fully appreciated (Hewitt, 1969), which is particularly evident when the probabilities of the occurrence of different geophysical events are included. In some instances, natural hazards lead to discrete events with independent probabilities, as might be the case with hurricanes and floods—whereas other events are linked, such as thunderstorms that bring hail, lightning, and/or tornadoes. The difficulties in multiple risk analysis are exacerbated when the probabilities are not independent (as the data in Table 8.3 attest), for example, a seiche or tsunami resulting from an earthquake. Not all earthquakes (even oceanic ones) cause tsunamis, but the probability of a tsunami is dependent on that of an earthquake or major slope failure, while the reverse is not true.

Some models have been developed to address multiple probabilities. Jacobs and Vesilind (1992) analyzed the many risks of environmental damage resulting from chemical spills, and their model was adapted for the analysis of independent multiple hazards in New Zealand (Montz, 1994). This work is based on the recognition that consideration of the uncertainties associated with the probability of dependent events is required, which is illustrated in Figure 8.6. As shown, hydrothermal eruptions can result from natural hydrogeological changes, or they may be caused by earthquakes or volcanic activity that forces the hydrogeological changes. The uncertainties associated with dependent probabilities certainly complicate attempts to develop multiple risk measures, but unless we take them into account we can neither fully understand nor manage risk comprehensively in a given area. Clearly, identifying the multiple hazards affecting a particular place is critical to understanding and ultimately managing the risks, as Cutter and colleagues (2000) demonstrate in their analysis of Georgetown, South Carolina, which in turn is based on Cutter's (1996) hazards of place model. These and other case studies point up the need for land use planning to reduce risk, which might be particularly applicable in the context of sustainable development (Bacon, 2012; United Nations Development Programme, 2004). The increasing emphasis on developing community resilience is an important step toward addressing the shortcomings discussed above associated with incorporating

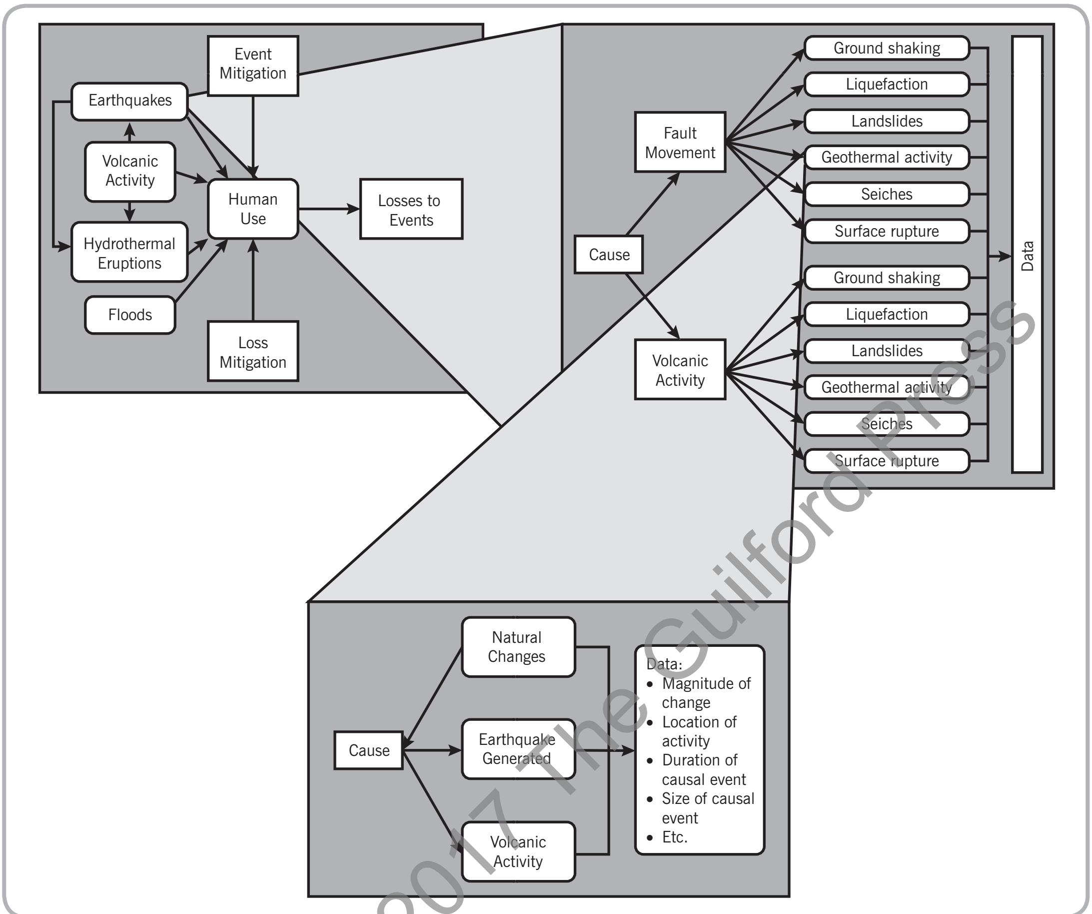

FIGURE 8.6. Dependent hazard probabilities. Not all natural hazards have independent probabilities of occurrence. The layers in this diagram illustrate some linkages in Rotorua, New Zealand. Numerous layers of data are required to develop the basis for analyzing scenarios of events. From Montz (1994).

uncertainty and multiple hazards into planning, as pointed out by the Committee on Increasing National Resilience to Hazards and Disasters (2012).

SUMMARY

It is tempting to lump all hazards together in risk analysis, but that does not usually work well in practice. There is no doubt technological and natural hazards are integrally related in that one type can cause, aggravate, or mitigate the other. Moreover, encountering multiple hazards at a single site inevitably increases the analytical complexities. When we are dealing with relationships among various types of risks or with multiple risks at a single location, the complex interactions among them increase the difficulties disproportionate to the number of risks being analyzed. Having presented the linkages between natural and technological hazards as well as those among different natural hazards at a single place, we focus in the remainder of this chapter on risk management for natural hazards. However, it is worthwhile to ask how the discussion might differ if the focus were on multiple hazards at a place.

Risk Management

No matter how risk is defined, risk governance and management seek to minimize, distribute, or share the potentially adverse consequences. Fra Paleo (2015a, p. 7) identifies four pillars of risk governance:

1. Sustainability, as a response to environmental degradation, resource depletion, and ecosystem deterioration;
2. Governance, as a reaction to government inability to address key societal and environmental problems;
3. Mitigation, as a means to avoid exposure and reduce vulnerability; and
4. Adaptation, as a response to expected and unexpected changes in environmental conditions.

As we have seen, each of these has some bearing on natural hazards and risk.

For individuals, risk management requires knowing the characteristics and magnitudes of the risks. This knowledge usually is gained from experience, and "the essence of risk assessment is the application of this knowledge of past mistakes (and deliberate actions) in an attempt to prevent new mistakes in new situations" (Wilson & Crouch, 1987, p. 267). Just as individuals want to reduce exposure to loss, so do private and public entities, including government at all levels, because of the number of people and amount of property at risk. As Morgan (1993, p. 35) so aptly put it, risk management "tends to force a society to consider what it cares about and who should bear the burden of living with or mitigating a problem once it has been identified." The term *risk management* describes a decision-making process that involves defining need, recognizing the options that are available and acceptable, and choosing an appropriate alleviation strategy. Creating a culture of response (Dyer, 2009), it could be argued, is necessary, and doing so successfully entails a full appreciation of risk. The picture was assessed by Renn and Klinke (2015, p. 19) in this way: "Anticipating the consequences of human actions or events (knowledge) and evaluating the desirability and moral quality of these consequences (values) are the core elements of risk analysis." For the purposes of discussion here, we focus on public risk management, but we also could consider private industry or individuals.

It is important to recognize that uncertainty plays an important role in risk management. First, there is considerable uncertainty associated with the scientific data gathered from extreme geophysical events (see Chapter 2); the relative size and return periods for particular events are not always easy to calculate, and other dimensions of geophysical events may be even more difficult to comprehend. Second, there is added uncertainty associated with information collected about humans and their activities. Whether public or private, risk management must take into account legal, technological, economic, social, and ethical considerations if truly effective policies are to be implemented. Gathering the necessary data adds considerably to the uncertainty and further contributes to management difficulties. When the physical and human sources of uncertainty are combined, the problem is often compounded several-fold.

Uncertainty also becomes an integral part of risk management when mitigation projects are implemented because the magnitude and significance of uncertainty are woven into policy. However, the analytical techniques essential to risk definition and the policymaking process become secondary. The potential errors emanating from uncertainty are subsumed within policy and, by default, are no longer considered important. Thus, there is an integral relationship between risk management and public policy, and, since a crucial aspect of risk management is adopting mitigation policies, they cannot be discussed separately. As a result, a number of policies are included in this chapter that were discussed earlier (in Chapter 6).

Elements of the Risk Management Process

The process of risk management is diagrammed in Figure 8.7. It begins with identifying the nature of the risk, a critical step though it may appear to be self-evident; there can be no attempt at risk analysis or management without having first identified the need for both. In the public sector, there also must be the political will to follow through with the rest of the process. If the commitment to risk management is weak or nonexistent or if there is strong opposition to using public resources to deal with the risk, then there will likely be no progress beyond this point. In the private sector, trade-offs are estimated, balancing investment in risk management against alternative investments. If risk management is found to have fewer benefits than costs, the process will come to an end. Of course, in both the public and private sectors, need can be revisited at any time, as frequently happens when more information becomes available. Ultimately, better information changes perceptions of risk management.

Identifying Exposure

Exposure can be defined in two primary contexts, physical and financial. Physical exposure includes spatial assessments of those areas at risk from geophysical events of given magnitudes. Risks at given locations differ according to the size and recurrence intervals of particular hazards, and because larger events usually affect larger areas, it is useful to know which types of events pose risks to an area and at what level of severity. (See the discussion on the physical characteristics of natural hazards in Chapters 2 and 3 as well as that on multiple hazards, above.) In this instance, exposure is defined in terms of the frequency and severity of occurrences. Because professional risk managers, especially insurers, deal with uncertainty by increasing the price, the greater the uncertainty, the higher the price; hence, the more accurately the nature of the risk can be described, the better (Estall, 1994).

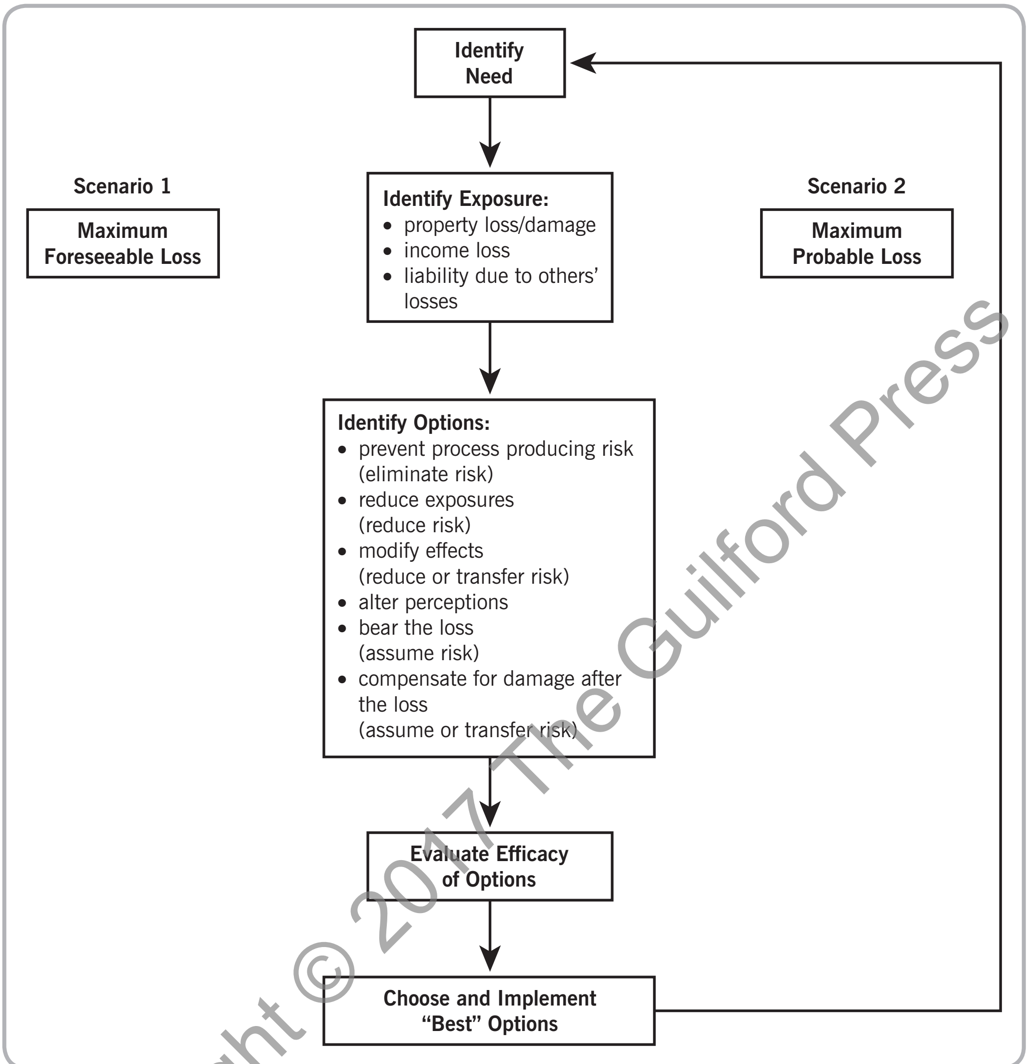

FIGURE 8.7. The risk management process. Each step requires decisions by policymakers. Many times this process is undertaken formally starting with a choice of scenarios to evaluate, as depicted here, but often it is an informal process in which the different stages are not easily discernible. From Burby et al. (1991) and Morgan (1993).

Financial exposure entails a risk management strategy to reduce financial loss. Thus, it is important to know the details of potential losses, such as the value and types of property at risk, the expected extent and types of damage, the amount of lost income, the damage to infrastructure, the cost of disrupted social and economic activities, and the expense of emergency responses. These losses must be assessed for public and private concerns and for various geographic areas. There also may be liability concerns if responsibility for the disaster can be traced to a specific cause. For example, if the failure of a levee leads to extensive damage, there may be legal action if it can be proved that the system failed because of inadequate maintenance or faulty construction.

Analyses of exposure entail a commitment of human and financial resources to the task. In many cases, resources are diverted to other activities for any number of reasons such as limited financial resources, which explains many differences among countries. Within countries and other political entities, there are issues that relate to the political will to act, the socioeconomic status of those at greatest risk, and risk perceptions. The discussion that follows is based on the best-case scenario, where, if resources are needed for analysis, they can be found.

Regarding the question of geographic exposure, hazardous areas can be mapped to show the probability of occurrence or some other risk measures. This is done for the flood hazard in the United States through the use of flood insurance rate maps (see Figure 6.3), which are based on hydrologic modeling. Using rainfall records of storm events to generate flood flows, the flow is routed downstream to determine the areas and depths of flooding for the 100- and 500-year events. The maps show technical risk based on the expected depth and probability of occurrence of the 100- and 500-year floods. These maps are then used to set insurance rates, based in turn on depth of flooding (risk) and type of property. It should be noted, though, that the accuracy of some hydrological maps has been publicly challenged (Bales & Wagner, 2009), and there continue to be calls for greater communication on risk assessments between experts and laypersons in this regard (Barredo, de Roo, & Lavalle, 2007; Pender & Neelz, 2007). Similar maps are constructed in coastal areas where hurricanes present a hazard and in earthquake zones.

Our ability to map spatial differences of risk is probably best developed for floods and hurricanes, and to some extent volcanoes and earthquakes (as shown in Figure 6.5). Other hazards, such as tornadoes, snowstorms, and drought, present more problems that add to uncertainty, in part because they are less well defined spatially. In addition, the secondary hazards associated with some geophysical events, such as earthquakes and thunderstorms, make the mapping of risk levels especially difficult. Still, some maps have been produced that detail the potential severity of various earthquake hazards (Erdik & Durukal, 2008; French & Isaacson, 1984). Areas at risk from volcanic mudflows and landslides are well mapped in some places, as are areas at risk of seismic shaking and liquefaction in San Francisco, Salt Lake City, and Portland, Oregon. Less detailed, but still useful, are the special studies zone maps in California (Cross, 1988).

Indices also have been developed to represent different levels of risk. In New Zealand, a standardized coastal sensitivity index (CSI) has been developed to identify coastal areas that "will be relatively more sensitive than others to potential impacts of climate change and coastal erosion" by using geomorphic and oceanographic variables (Goodhue et al., 2014, p. 24). With rising sea levels, more attention to the dynamic nature of coastal risks would appear to be an imperative.

Many of these studies do not address the probability issue directly, but rather focus on what likely will happen, where it will occur, and when an event might take place. For instance, if it is estimated that a geophysical event of magnitude *x* will affect an area of size *y,* the human impact will be assessed based on an inventory of the number of structures and people in the area. A refined analysis would include a determination of structure types, construction standards, and the ability of the population to undertake remedial action. It is also important to determine the probability of occurrence of an event of magnitude *x* in order to have a measure of exposure against which the costs and benefits of various risk management options can be compared.

An inventory of property at risk is necessary in order to determine financial exposure. Typically, property is categorized by its estimated vulnerability to damage, involving such considerations as the type of construction material used, the age of the structure, and the number of stories. Public versus private buildings are differentiated, as are each building's various uses. Because of the potentially large financial exposure, public infrastructure is particularly important but problematic. It comprises systems with varied components exhibiting different vulnerability characteristics (Burby et al., 1991; Little, 2002), and, because these systems usually consist of networks, the probability of failure of one node or link affects many other nodes and links. In 1994 and 1995, the destruction of bridges during floods and earthquakes in California greatly exacerbated problems in the affected communities. Thus, damage to the public infrastructure can also increase the damage to other types of property.

Having determined spatial variations in risk and having completed an inventory of the property at risk, the two can be combined to analyze potential losses. The precision of results is dependent on the quality of the data, and clearly a GIS or some other data management system facilitates processing, given the volume and complexity of the data. Indeed, the great advances made in GIS over the past 30 years or so have added substantially to our arsenal of tools available to analyze risk, and HAZUS-MH takes advantage of these capabilities to provide needed analyses for some hazards. Risks are digitized and mapped, and the relationships among variables plotted and presented.

Certainly GIS presents many opportunities to enhance integrative approaches to both understanding and more precisely delineating risk as it pertains to exposure and even potential relief strategies in disasters. In an examination of multiple hazards in Tampa Bay, studies found that those regarded as most socially vulnerable do not live in the areas of greatest geophysical risk, which offers new insights to possible risk reduction (Montz & Tobin, 2003). Chen, Blong, and Jacobson (2003) also demonstrated the value of integrating data on the physical environment with socioeconomic data to assess risk with respect to brush fires. Other researchers' work has also clearly demonstrated the value of such high-powered computer-based programs (Amdahl, 2001; Greene, 2002; Monmonier, 1997; Sahu, n.d.).

Like all models, however, there are also constraints on the use of these techniques, particularly in relation to the quality of the data that are used (McMaster, Leitner, & Sheppard, 1997). Tobin, Hughey, and Miller (2004), for example, used the HAZUS-MH model to plot losses that might have occurred in Tampa Bay had Hurricane Charley held to its originally projected path. While the model was subject to considerable error at the time it was used, results did indicate the types of structures and facilities that would have been devastated. Refinements to the HAZUS models will doubtless improve our estimates of future risks and losses. Similarly, GIS is now often regarded as a solution rather than simply a tool for analysis. With this in mind, Carrara, Guzzetti, Cardinali, and Reichenbach (1999) cautioned that: (1) computer-generated maps are considered more accurate and credible than hand-drafted ones even though conversion of data to digital form may incorporate random or systematic errors; (2) a map portraying natural resources or hazards obtained by data manipulation within a GIS is assumed to be more objective and unbiased than other maps; and (3) the handling of geographical data in a GIS is simplified for users who are not experts in technology and not knowledgeable about the theory underlying GIS. Thus, it is argued that technology can lend an air of infallibility and scientific validity that goes beyond the reliability and accuracy of the data. It is possible, then, that the technological fix (discussed in Chapter 4) might be replaced by a "cybernetic simplification," with consequent unfavorable impacts on risk analysis and risk reduction (Tobin & Montz, 2004).

Using systems such as this, scenarios may be modeled to evaluate potential exposures under different conditions. Two such scenarios are shown in Figure 8.7, estimating maximum foreseeable losses, or what might be called the "worst-case analysis," and maximum probable losses, or "the worst loss to be expected under 'average' conditions" (Burby et al., 1991, p. 65); many other scenarios could be evaluated as well. The goal of such analysis, however, is an overall measure of the magnitude of risk to which an area is exposed. If the risk is not high—or at least widely perceived to be not high—then the risk management process ends (for now) with no action taken. However, if decision makers believe that the risk is unacceptably high, risk management options will be identified and evaluated.

Identifying and Evaluating Options

There are several ways in which risks can be managed, including eliminating them, reducing them, transferring them, and assuming (i.e., bearing) them (Burby et al., 1991). Within these categories there are further options, as shown in Figure 8.7. As with identifying exposure, the implications of these options vary, depending on the risk threshold under consideration, identified here by the maximum foreseeable and maximum probable loss. In addition, not all options are necessarily available at a given place at a given time. Lack of available resources, limited technological capabilities, lack of interest by outside investors, and a population that has (or believes it has) no power to effect change are among the reasons options may be unavailable. Indeed, one might question what criteria should be included in risk evaluation (Fra Paleo, 2015c).

With most hazards, it is not possible to eliminate the risk completely by modifying the physical processes. With floods, a river can be controlled to the extent that the probability of high-frequency events is greatly reduced, but the ability to control low-probability floods is questionable. The 500-year flood remains a threat, and this event would certainly exceed most structural designs. Ability to control the physical environment is even more constrained with such other geophysical events as earthquakes and tornadoes. Nevertheless, risk can be reduced by adopting safety measures or by avoiding or eliminating risky activities, but it might involve large investments that are not justified in light of the technical risk. It is usually only for high frequency–high consequence events that major investment would be considered; even then, the benefits would have to be significant. More often, efforts focus on reducing risk to an acceptable level rather than eliminating it completely.

Exposure can be reduced by limiting activities in hazardous areas. For instance, building on floodplains, in seismically active areas and along coasts in unprotected zones, can be avoided, which would reduce levels of exposure. Of course, the level of acceptable risk must be defined first. In the United States, development within a designated 100-year floodplain is restricted; the same is true in designated hurricane hazard areas and in tsunami run-up zones. For hazards with less well-defined zones, building codes can reduce exposure. Tie-down regulations in tornado-prone areas and landscaping requirements in areas subject to chaparral fires are two examples. This sort of action both reduces exposure and modifies effects (or losses). Thus, altered locations, materials, and types of buildings should be considered in estimating probable losses from events.

Another way to reduce exposure—especially financial exposure—is by transferring the risk, which also can modify the adverse financial effects of an event. The most common means of transferring risk is through insurance. For instance, local governments frequently carry commercial insurance for damages to real and personal property (Burby et al., 1991). Insurance provides some certainty that funds will be available to cover losses incurred from an event; for a fixed annual cost, those at risk can meet unbudgeted costs of a catastrophic nature. Of course, the greater the risk and the greater its uncertainty, the greater the annual cost of premiums. Indeed, "some risk exposures are apparently so unattractive to insurers, that coverage is not readily available or, otherwise, only at an outrageous price" (Estall, 1994, p. 30), as evidenced in Florida following several hurricanes. The insured are also taking a risk, namely, that the funds will be available when needed. If the insurers are not solvent or if claims exceed reserves and reinsurance is unavailable, then the insured lose. There are many instances of insurance companies failing because of disasters. In the United States during the 1920s, a group of insurance companies was forced out of business because of heavy losses (Rommel, 1960; Vaughn, 1971). That pattern has continued, especially as insured losses for natural disasters vary so much from year to year, with extremes associated with events like Hurricane Katrina (2005) and Superstorm Sandy (2012). The effect of Hurricane Andrew in 1992 on the insurance industry is illustrated by reports that eight insurance companies with significant coverage in Florida collapsed within months of the hurricane (see Table 8.4) (Flavin, 1994). This pattern has been repeated on several occasions. In 2004 Florida experienced four hurricanes in 6 weeks, and during the following years insurance by several major companies was severely curtailed.

There are many problems with relying on insurance as a risk management option. First, insurance may not be available for some hazards. In the United States, flood insurance was not generally available until passage of the National Flood Insurance Act of 1968. A person or community was unlikely to purchase flood insurance unless the risk was perceived as substantial, and hence individuals or communities who chose

TABLE 8.4. Insured Losses from Natural Disasters in the United States, 1984–1993

Year	Total insured losses ($)
1984	1,500,000,000
1985	2,900,000,000
1986	900,000,000
1987	900,000,000
1988	1,400,000,000
1989	7,600,000,000
1990	2,800,000,000
1991	4,700,000,000
1992	23,000,000,000
1993	5,700,000,000

Note. Data from Property Claims Services, as cited by Flavin (1994).

to purchase flood insurance generally resided in high-risk areas. The private insurance industry was unwilling to accept such a great risk, for with such homogeneity of risk, a disaster produces a large number of claims. Consequently, when the NFIP was implemented, flood insurance was made available by the federal government at subsidized rates, provided that communities met certain floodplain management requirements. Since its inception, flood insurance has moved back into the private sector, but companies are reinsured by the government, which protects them against catastrophic losses. Further changes were made in 2012 when Congress passed the Flood Insurance Reform Act, which requires the NFIP to raise rates (premiums) to reflect "true flood risk" and make the program financially stable (Federal Emergency Management Agency, 2013c). In other words, government subsidies are being phased out. This has led to criticism of the federal government, and two states (at the time of writing) have thus far petitioned to change the law (Martin, 2013).

Still, the perception of risk is such that residents sometimes procrastinate in taking out insurance until flooding is imminent, and then once the flood has passed, they often drop their insurance. This may represent rational behavior for downstream residents who may have several days or even weeks of warning, but it does not work for those in flash flood environments. To close this loophole, FEMA amended NFIP rules to require a 30-day waiting period for flood insurance to take effect (Federal Register, 1995). In other countries, flood insurance is sometimes available through the private market. For instance, in Australia flood insurance is available in many but not all locations, depending in large part on the availability of flood maps, which are generally the responsibility of local governments (Insurance Council of Australia, 2010). While there is great variation from state to state within Australia, it is estimated that just over 50% of insurance policies include flood coverage, with Queensland accounting for the highest proportion (Mason, 2011).

Earthquake insurance is another story. It is available in the United States only through the private market, and (as would be expected) where the risk is high it is very expensive. People living in earthquake-prone areas must pay the full cost of the insurance, and, as a result, household coverage in California is not extensive. Although wide ranges are reported among counties, it is estimated that adoption rates for the state are well below 50% of homeowners (Palm, 1995) and more like 33% in 1996, according to Cummins (2006). Following the earthquakes in California in 1994, the insurance industry asked that all homeowners' policies across the country include earthquake insurance, which would reduce premiums for those in high-risk areas and distribute the costs across a much broader population, but to date this has not occurred. However, the California Earthquake Authority was created to provide earthquake insurance to residents of the state. By 2003, only an estimated 14% of homeowners had insurance, ostensibly because of the high costs, even though they reflect the risk (Cummins, 2006).

Risk also can be transferred from one level of government to another by making another organization or agency responsible for emergency action. In the United States, the declaration of a disaster area effectively transfers responsibility. At the national level, a presidential declaration means that financial assistance in the form of grants and loans becomes available from the federal government. For example, following Superstorm Sandy in 2012, more than US$10 billion was provided to individuals and governments in New Jersey and New York. The NFIP also represents an intergovernmental transfer of risk because of the way in which the federal government underwrites it, although this has been changing. At the state level, governors can declare disaster areas, thereby permitting state aid and mobilization of other resources. Of course, such funds do not cover all losses, so other means beyond intergovernmental transfers of risk must be found as well.

In industrialized countries, relief frequently is applied to restoration of infrastructure, but it is also available to homeowners and other victims. International relief is another form of risk transference from one government or agency to another. As discussed in previous chapters, there are many problems associated with international aid, including the question of whether it actually transfers risk or allows it to continue to increase, at least for part of the population.

There are other ways to transfer risk. One example is a mutual pool into which there are a number of contributors. Its purpose is to build up sufficient reserves to meet a claim by any contributor, and claims cannot be made until an adequate pool exists. Usually, contributors self-insure for high frequency–low consequence events, whereas low frequency–high consequence events may wipe out a pool entirely. It is the moderate frequency–moderate consequence events for which this option is best suited (Burby et al., 1991). Pools work well because costs can be kept relatively low due to risk-sharing among participants, but they can backfire if one participant is at greater risk than the others and depletes the reserves; that is, if risk among participants is diverse, some participants may end up subsidizing the high-risk participant.

Research in the United States has shown a reluctance by local officials to invest in such a pool (Burby et al., 1991). On the other hand, in New Zealand the central government encourages communities to prepare themselves for losses through the Local Authority Protection Program Disaster Fund, established in 1993, which involves insuring community infrastructure through a kind of mutual pool (Montz, 1994). Of course, it is not known whether this pool will have sufficient funds when needed by a community or communities, but the central government will pay 60% of costs once a threshold has been exceeded. The Christchurch earthquakes of 2010 and 2011 have put considerable stress on these resources.

New Zealand provides an interesting mix of methods through which exposure is reduced and on how it has evolved over time. Physical exposure is reduced through land use restrictions and building codes, notably under the Resource Management Act of 1991 (and subsequent amendments) and the Building Act of 2004. The Resource Management Act concerns land use and the placement of buildings, and the Building Act covers construction. There are some difficulties in how these two acts work together in practice, but both take into consideration natural hazards, particularly flooding.

More important is the way in which means to reduce financial exposure have changed in light of increased losses and the decreased willingness of the central government to continue to underwrite them. In 1944, New Zealand passed the Earthquake and War Damage Act. All homeowners with fire insurance paid 5 cents per NZ$100 coverage into a common fund on the premise that, because earthquake damage was widespread and unpredictable, the risk could reasonably be spread among all homeowners (O'Riordan, 1971). Following public pressure, especially from those in areas of lower risk, and some damaging events, the act was amended in 1949 to cover other natural events. Thus, New Zealand thereby acquired a national insurance program for natural hazards.

In 1993, New Zealand passed the Earthquake Commission Act, which was consistent with the central government's interest in reducing postdisaster exposure and in having local and regional governments take more responsibility for the consequences of land use decisions. Among other changes, the Act restructured the existing Earthquake Commission and put a cap on payments from its fund, ending the national insurance program for natural hazards. Instead, under the new Earthquake Commission and the National Disaster Recovery Plan of 1992, local and regional governments must look to other ways of reducing exposure through land use decisions, private insurance, or other means. As noted in Chapter 7, under these acts, regional and district councils can create zones to require specific conditions to be met in order to gain consent to develop, among other controls.

A final option is to assume the risk. On a global scale, this is probably the most common option because of a lack of access to alternatives. Indeed, bearing the cost is the only choice that many have until or unless some form of relief becomes available. Even in places where there are choices, assuming the loss may be the only practical alternative because of the high cost of eliminating or transferring risk or the lack of technical and economic feasibility. In some cases, risk may be eliminated or transferred up to some level, beyond which it is assumed. For individuals, assuming risk involves drawing on personal resources to cover losses when an event occurs. Of course, some people choose this option in spite of the availability of other choices because of how they perceive the risk and their own vulnerability. Compared to the inputs required for other options, they are comfortable living with the risk to which they see themselves exposed.

Governments face a different situation with regard to assuming risk. Most obvious is the fact that their losses can be very large, due, among other things, to damaged infrastructure. In addition, since repairs to the public infrastructure can affect the recovery process, it is critical that governments be able to overcome their losses as quickly as possible. Having said that, the costs of the other options may be too high for a government to commit funds to them at a given level of risk. Governments also may choose to eliminate or transfer part of the risk and to assume the risk that remains; since it does not make economic sense to insure against absolutely all risk and because we may not completely understand the nature or magnitude of the total risks at a given place, assuming risk makes sense.

There are several ways in which governments assume risk. One is simply by default, resulting from lack of knowledge of a risk. Officials also may decide to assume all or part of the risk to which an area is exposed, which can be accomplished through a self-insurance program in which reserve funds exist to cover losses. Such funds can be created through various devices, such as accumulating contingency funds based on a percentage of expenditures or some other formula, or financing through capital markets (Burby et al., 1991). Obviously, the ability of government to dedicate funds to such a reserve depends on a community's financial situation. The success of this option depends on the ability of a community to determine its needs with reasonable accuracy, based on the risk to which it is exposed.

Comparing and Choosing Options

The options detailed above are not mutually exclusive. Assuming that choices are available, individuals, governments, and the private sector usually favor some mix of options. The selection of an appropriate mix is based on several factors, including exposure, the frequency and severity of events, and cost effectiveness. Furthermore, we must recognize that "which strategy is best depends in large part on the attributes of the particular risk" (Morgan, 1993, p. 38). When it is difficult to eliminate risk because of cost or technical feasibility or both, another strategy or set of strategies is needed. This is the case with earthquakes, where we cannot eliminate the risk by modifying the geophysical process, and with floods, where we can control some but not all hydrological processes.

The choice of options also is bounded by the results of formal or informal cost–benefit analysis. It is risky to invest money, personnel, or other resources in an activity to protect against future losses from an event, the occurrence of which is probabilistic (see Chapter 7), a problem that is exacerbated by multiple hazards. Thus, measures of cost effectiveness and risk come into play.

Yet, we know that most local governments do not take adequate measures to protect against financial loss. The reasons include "inadequate appreciation of the potential for catastrophic losses, inadequately developed risk management capacity, and insufficient resources for loss prevention" (Burby et al., 1991, p. 118). The risk management process is a complex one involving economic, technical, and perceptual factors. Though the options are well developed and, in theory, well understood, adoption is not. In a study of the degree to which risk management had been successfully implemented after the 1964 Alaska earthquake, two obstacles to success were identified, organizational and political (Natural Hazards Research and Applications Information Center, 1985). Organizational obstacles were associated with scientific uncertainty, a decision-making model based on the rational actor, and ambiguous policy directives. Political obstacles were more difficult to overcome; they included leaders lacking knowledge, a lack of commitment to implementation on the part of political leaders, and an inadequate definition of what level of government was or should be responsible for it. This has not changed much in the intervening decades, nor does it apply to only one event—these obstacles are widespread (Sperling & Szekely, 2005).

Although risk management appears to be a straightforward process (see Figure 8.7), it is anything but that in practice. A person, community, or industry can go through the process in a systematic, logical sequence, but the ultimate decision on which strategy to adopt brings in other factors. With governments, these are political factors. In addition, it must be recognized that a decision to do nothing is in fact a decision to assume the risk or perhaps to transfer it through relief expected from other levels of government. However, this is not risk management, but avoidance, which too many times may be seen as the most cost-effective option based, of course, on a restricted view of cost effectiveness. To higher levels of government, it may not be cost-effective, and if these higher levels of government decide to implement only what they view as cost-effective, they may not accept risk transfers in the future.

All risk choices are compromised in some way, presenting difficulties for disaster preparedness. May (1989) summarized such problems in cultural, systemic, and individual models. Inherent in the cultural model are conflicts that surround decision making and stem from the need to compromise. Given varied interests and perceptions, not everyone will be completely satisfied, and the risk will not necessarily be minimized. Similarly, societies' demand for goods and services adds to community risks, while individuals generally miscalculate risk. Managing risk is intrinsically difficult.

CONCLUSION AND INTEGRATION

Risk analysis and management transcend hazard types. While specific components of analysis differ among hazards in ways related largely to the ability to identify physical exposures, the process of identifying, choosing, and implementing risk management strategies does not really differ. However, there are many important differences in organizational and political structures that serve either to facilitate or complicate the process. Added difficulties lie in identifying the extent to which an area is at risk (within acceptable levels of accuracy). It is little wonder that, if they are managed at all, risks tend to be managed on a hazard-by-hazard basis. Certainly some actions and strategies transcend particular hazards, such as emergency preparedness plans. However, other forms of risk management—such as transferring, eliminating, or assuming risk—usually are undertaken with a particular hazard in mind. It is the perceived risk of different hazards, as opposed to technical measures of risk, that motivates managers to attempt risk reduction.

Risk ends up in the policy arena because it is through policies—especially public policies—that risks most frequently are managed. Various groups are exposed directly and indirectly to a public risk, and losses can far exceed the abilities of those in affected areas to underwrite them. Furthermore, different levels of government and different groups have different definitions of risk; though they may all use the same term, they are often discussing different types of risk. As a result, responsibility frequently falls to the public sector, although it is essential that individuals and nongovernmental organizations play a role (Christoplos, Mitchell, & Liljelund, 2001). This does not make it any easier to manage risk, and indeed it may be a complicating factor. However, it is there that considerations of technical, social, economic, political, and geophysical factors can come together. In addition, the scale of analysis is important with respect to risk and vulnerability. As Birkmann (2007, p. 30) suggests:

> One of the most important goals of developing tools for measuring vulnerability is to help bridge the gaps between the theoretical concepts of vulnerability and day-to-day decision making. Therefore, it is important to view vulnerability as a process. Within this process, measures and instruments need to be defined which allow us to assess the past, current, and potential future areas and people at risk or vulnerable. Besides the generation of new and better data for global and local vulnerability and risk assessment, it is also important to strengthen co-operation and exchange between global and local approaches.

Four points stand out (Tobin & Montz, 2009, p. 419):

1. Risk can be explained through greater understanding of the probability of occurrence of particular events, the populations exposed, their various vulnerabilities and the availability and effectiveness of coping strategies to mitigate negative impacts.
2. Risk is dynamic, varying over time and space. Some risks are random while others are more predictable.
3. Risk can only be fully assessed through an examination of both the physical forces, such as those associated with extreme events, and the human environment, including societal norms and structures that influence the behavior and perceptual outlooks of individuals who influence decision making.
4. Technology has greatly improved our understanding of statistical risk and our ability to evaluate risk spatially and temporally. Communicating that risk is still a major challenge, yet a critical one, because risk and uncertainty are part of life.

To put this into practice, Fra Paleo (2015c, p. 252) highlights the risk policy principles that are derived from the Hyogo Framework for Action (International Strategy for Disaster Reduction, 2005):

- Ensure that the disaster risk reduction is a national and local priority with strong institutional backing for implementation.
- Identify, assess, and monitor disaster risks and enhance early warning.
- Use knowledge, innovation, and education to build a culture of safety and resilience at all levels.
- Reduce underlying risk factors.
- Strengthen disaster preparedness for effective response at all levels.

In the final analysis, it is clear that we must all learn to live with a degree of risk (International Strategy for Disaster Reduction, 2004). No place in the world is completely safe, and the ever-changing socioeconomic conditions combined with evolving physical forces, such as global climate change, together create a dynamic environment with which we must contend. Being prepared, developing mitigation strategies, and planning for disaster situations are the ways to deal with the elusive nature of risk. Confounding this is the issue of fairness—does a greater understanding of risk translate to fair and equitable policies? Johnson, Penning-Rowsell, and Parker (2007) indicate that this is not always the case. In dealing with the flood hazard in the United Kingdom, they showed (through the use of three different social justice models) that those national strategies that appear to be most technically and economically effective are not necessarily fair, and in the end they called for government funding of nationally consistent nonstructural strategies.

The integration of risk and policy, therefore, is an essential tool in helping to overcome disaster losses and provide for all those in need if we are to truly reduce risk, minimize vulnerability, and create resilient communities.