4 Natural Hazards: An Overview

Earthquake damage, January 1995, Kobe, Japan. (*Shinya Inui/Friday/Sygma Photo News*)

The catastrophic January 1995 earthquake that devastated Kobe, Japan, causing damages in excess of $100 billion and the deaths of more than 5000 people, was a "wake-up call": our cities are vulnerable to natural hazards on a scale we had not previously envisaged. Japan was confident that it was prepared to respond to earthquakes, and yet they apparently were caught off-guard. Emergency relief did not arrive until about 10 hours after the earthquake, and buildings and other structures thought relatively safe failed catastrophically. Not only earthquakes have potential for catastrophe; in 1998 Hurricane Mitch—with winds in excess of 270 kilometers per hour—struck Central America, devastating the landscape as homes, schools, roads, and bridges were blown down or washed away by torrential rains. More than 11,000 people in Nicaragua and Honduras were killed, with at least that many more missing. Perhaps as much as one-third of the total population of Honduras were left homeless! The catastrophic effects of Hurricane Mitch were particularly devastating because much of the landscape has been altered by human use, such as deforestation and urbanization. As human population continues to increase during the twenty-first century, the effects of natural processes, such as hurricanes, floods, landslides, earthquakes and volcanic eruption, will become more damaging to human society simply because more people are at risk.

4.1 Hazards as Natural Processes

During the past two decades, natural disasters, such as earthquakes, floods, cyclones, and hurricanes, have killed several million people on this planet, with an average annual loss of life of about 150,000. The financial loss probably exceeds $20 billion and does not include social losses, such as loss of employment, mental anguish, and reduced productivity.

LEARNING OBJECTIVES

The study of hazardous processes constitutes one of the main activities of environmental geology. Learning objectives for the chapter are:

- *To know the conditions that make some natural earth processes hazardous to people.*
- *To understand how a natural process that gives rise to disasters may also be beneficial to people.*
- *To make a preliminary acquaintance with the various natural processes that constitute hazards to people and property.*
- *To understand the requirements for predicting natural disasters.*
- *To know the basic components of risk assessment for natural hazards.*
- *To become familiar with people's perceptions of and adjustments to hazards.*
- *To be able to discuss the impact and recovery from natural disasters and catastrophes.*
- *To understand why increase in population and changing land use, particularly in developing countries, increases the threat of loss of life and property from natural disasters.*

Web Resources

Visit the "Environmental Geology" Web site at www.prenhall.com/keller to find additional resources for this chapter, including:

- Web Destinations
- On-line Quizzes
- On-line "Web Essay" Questions
- Search Engines
- Regional Updates

Two individual disasters—a cyclone accompanied by flooding in Bangladesh in 1970 and an earthquake in China in 1976—each claimed more than 300,000 lives. In 1991 another cyclone struck Bangladesh, claiming another 145,000 lives (Figure 4.1). The 1995 earthquake in Kobe, Japan, claimed more than 5000 lives, destroyed many thousands of buildings, and caused more than $100 billion in property damage (Figure 4.2). These terrible disasters were caused by natural hazards that have always existed—atmospheric disturbance and tectonic movement—but their extent was affected by human population density and land-use patterns.

Natural hazards are basically natural processes. These processes may become hazardous when people live or work in areas where these processes occur, or when land-use changes, such as urbanization or deforestation, increases the occurrence and/or magnitude of processes such as flooding or landsliding. It is the environmental geologist's job to identify potentially hazardous processes and make this information available to planners and decision makers so that they can formulate various alternatives to avoid or minimize the threat to human life or property. However, the naturalness of hazards is a philosophical barrier that we encounter whenever we try to minimize their adverse effects.

The *impact* of a disastrous event is in part a function of its magnitude (amount of energy released) and frequency (recurrence interval), but it is influenced by many other factors,

▲ **FIGURE 4.1** Aftermath of the 1991 cyclone that devastated Bangladesh, killing approximately 145,000 people. (*Bartholomew/Liaison Agency, Inc.*)

▲ **FIGURE 4.2** The earthquake that struck Kobe, Japan, in January 1995 had a devastating effect on the people of the city while causing in excess of $100 billion damage. More than 5,000 people were killed. (*Mike Yamashita/Woodfin Camp and Associates*)

A CLOSER LOOK The Magnitude-Frequency Concept

The **magnitude-frequency concept** is the assertion that there is generally an inverse relationship between the magnitude of an event and its frequency. In other words, the larger the flood, the less frequently such a flood occurs. The concept also includes the idea that much of the work of forming the earth's surface is done by events of moderate magnitude and frequency, rather than by common processes with low magnitude and high frequency or extreme events of high magnitude and low frequency.

As an analogy to the magnitude-frequency concept, consider the work of logging a forest done by resident termites, human loggers, and elephants. The termites are numerous and work quite steadily, but they are so small that they can never do enough work to destroy all the trees. The people are fewer and work less often, but being stronger than termites they can accomplish more work in a given time. Unlike the termites, the people can eventually fell most of the trees (Figure 4.A). The elephants are stronger still and can knock down many trees in a short time, but there are only a few of them and they rarely visit the forest. In the long run the elephants do less work than the people and bring about less change.

In our analogy it is humans who, with a moderate expenditure of energy and time, do the most work and change the forest most drastically. Similarly, natural events with a moderate energy expenditure and moderate frequency are often the most important shapers of the landscape. For example, most of the sediment carried by rivers in regions with a subhumid climate (most of the eastern United States) is transported by flows of moderate magnitude and frequency. However, there are many exceptions. In arid regions, for example, much of the sediment in normally dry channels may be transported by rare high-magnitude flows produced by intense but infrequent rainstorms. Along the barrier-island coasts of the eastern United States, high-magnitude storms often cut inlets that cause major changes in the pattern and flow of sediment.

▲ **FIGURE 4.A** Human beings with our high technology are able to down even the largest trees in our old-growth forests. The lumberjack shown here is working in a national forest in the Pacific Northwest. (*William Campbell/Sygma Photo News*)

including climate, geology, vegetation, population, and land use. In general, the frequency of such an event is inversely related to the magnitude: Small earthquakes, for example, occur more often than do large ones (see *A Closer Look: The Magnitude-Frequency Concept*).

The 1990s were designated by the United Nations as the International Decade for Natural Hazards Reduction. The objective of the continuing UN program is to minimize loss of life and property damage resulting from natural hazards. Reaching this objective will require measures to mitigate both specific physical hazards and the biological hazards that often accompany them. For example, after earthquakes and floods, water may be contaminated by bacteria, increasing the spread of diseases.

Benefits of Natural Hazards

It is ironic that the same natural events that take human life and destroy property also provide us with important benefits. River flooding supplies nutrients to floodplains, as in the case of the Mississippi River or the Nile Delta prior to the building of the Aswan Dam. Flooding also causes erosion on mountain slopes, delivering sediment to beaches from rivers and flushing pollutants from estuaries in the coastal environment. Landslides bring benefits to people when landslide debris form dams, making lakes in mountainous areas. These lakes provide valuable water storage and are an important aesthetic resource.

Volcanic eruptions, while having the potential to produce real catastrophes, provide us with numerous benefits. They often create new land: The Hawaiian Islands, for example, are completely volcanic in origin (Figure 4.3). Nutrient-rich volcanic ash may settle on existing soils and quickly become incorporated in them. Earthquakes, too, provide us with valuable services. When rocks are pulverized during an earthquake, they may form an impervious clay zone known as **fault gouge** along the fault. In many places, fault gouge has formed a groundwater barrier upslope from a fault, producing a natural subsurface dam and a water resource. Earthquakes are also important in mountain building and thus are directly responsible for many of the scenic resources of the western United States.

Death and Damage Caused by Natural Hazards

When we compare the effects of various natural hazards, we find that those that cause the greatest loss of human life are not necessarily the same as those that cause the most extensive property damage. Table 4.1 summarizes selected information about the effects of natural hazards in the United States. The largest number of deaths each year is asso-

(a) (b)

▲ **FIGURE 4.3** New land being added to the island of Hawaii. The plume of smoke in the central part of the photograph is where hot lava is entering the sea (a). Close-up of an advancing lava front near the smoke plume (b). (*Edward A. Keller*)

ciated with tornadoes and windstorms, although lightning, floods, and hurricanes also take a heavy toll. Loss of life due to earthquakes can vary considerably from one year to the next, as a single great quake can cause tremendous human loss. It is estimated that a great earthquake in a densely populated part of California could inflict $100 billion in damages while killing several thousand people (1). The 1994 Northridge earthquake (large but not great) in the Los Angeles area killed some 60 people and inflicted about $20 to $30 billion in property damage. Property damage from individual hazards is considerable. Floods, landslides, expansive soils, and frost each cause mean annual damages in the United States in excess of $1.5 billion. Surprisingly, expansive soils are one of the most costly hazards, causing more than $3 billion in damages annually.

Table 4.1 Effects of selected hazards in the United States

Hazard	Deaths per Year	Occurrence Influenced by Human Use	Catastrophe Potential[b]
Flood	86	Yes	H
Earthquake[a]	50+?	Yes	H
Landslide	25	Yes	M
Volcano[a]	<1	No	H
Coastal erosion	0	Yes	L
Expansive soils	0	No	L
Hurricane	55	Perhaps	H
Tornado and windstorm	218	Perhaps	H
Lightning	120	Perhaps	L
Drought	0	Perhaps	M
Frost and freeze	0	Yes	L

[a]Estimate based on recent or predicted loss over 150-year period. Actual loss of life and/or property could be much greater.
[b]Catastrophe potential: high (H), medium (M), low (L).

Source: Modified after G. F. White and J. E. Haas. 1975. *Assessment of Research on Natural Hazards*. Cambridge, MA: The MIT Press.

An important aspect of all natural hazards is their potential to produce a **catastrophe,** defined as any situation in which the damages to people, property, or society in general are sufficient that recovery and/or rehabilitation is a long, involved process (2). Table 4.1 gives the catastrophe potential—high, medium, or low—for the hazards considered. The events most likely to produce a catastrophe are floods, hurricanes, tornadoes, earthquakes, volcanic eruptions, and large wildfires. Landslides, because they generally cover a smaller area, have a moderate catastrophe potential. The catastrophe potential of drought is also moderate: Though a drought may cover a wide area, there is usually plenty of warning time before its worst effects are experienced. Hazards with a low catastrophe potential include coastal erosion, frost, lightning, and expansive soils (2).

The effects of natural hazards change with time because of changes in land-use patterns, which influence people to develop on marginal lands; urbanization, which changes the physical properties of earth materials; and increasing population. Damage from most hazards in the United States is increasing, but the number of deaths from many hazards is decreasing because of better prediction, forecasting, and warning of hazards.

4.2 Evaluating Hazards: Disaster Prediction and Risk Assessment

Learning how to predict disasters so we can minimize human loss and property damage is an important endeavor. For each particular hazard we have a certain amount of information—

enough in some cases to forecast events accurately. When there is insufficient information to make accurate predictions, the best we can do is to locate areas where disastrous events have occurred and infer where and when similar future events might take place. If we know both the probability and the possible consequences of an event occurring at a particular location, we can assess the risk the event poses to people and property, even if we cannot accurately predict when it will occur.

Disaster Prediction and Warning

The effects of a specific disaster can be reduced if we can forecast the event and issue a warning. Attempting to do this in a given situation involves most or all of the following elements: identifying the location of a hazard, determining the probability that an event of a given magnitude will occur, observing precursor events, predicting the event, and issuing a warning.

Location For the most part, we know *where* a particular kind of event is likely to occur. On a global scale, the major zones for earthquakes and volcanic eruptions have been delineated by mapping earthquake epicenters and recent volcanic rocks and volcanoes. On a regional scale, we know from past eruptions which areas in the vicinity of certain volcanoes are likely to be threatened by large mudflows or ash in the event of future eruptions. This risk has been delineated for several Cascade volcanoes, including Mt. Rainier, and for specific volcanoes in Japan, Italy, Colombia, and elsewhere. On a local scale, detailed work with soils, rocks, and hydrology may identify slopes that are likely to fail (landslide) or where expansive soils exist. Certainly we can predict where flooding is likely to occur, from the location of the floodplain and such evidence from recent floods as the flood debris and high-water line.

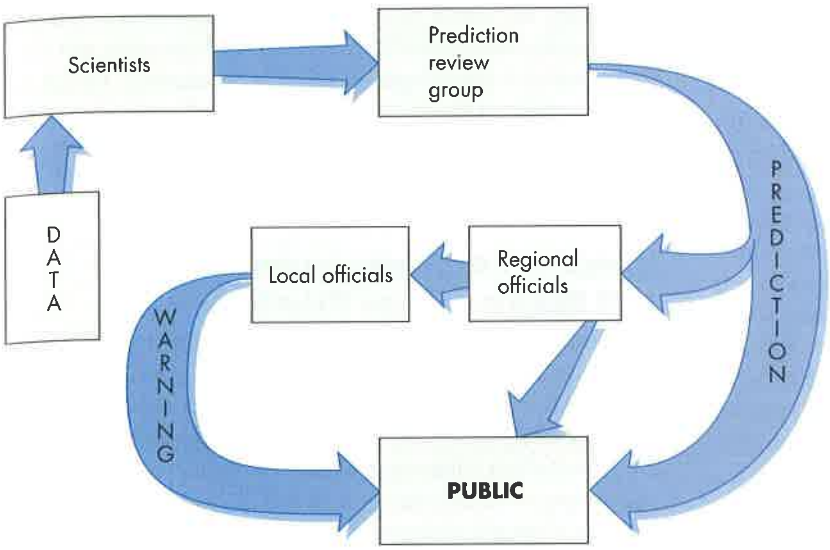
Probability of Occurrence Determining the probability that a particular event will occur in a particular location within a particular time span is an essential part of a hazard prediction. For many rivers we have sufficiently long records of flow to develop probability models that can reasonably predict the average number of floods of a given magnitude that will occur in a decade. Likewise, droughts may be assigned a probability on the basis of past occurrence of rainfall in the region. However, these probabilities are similar to the chances of throwing a particular number on a die or drawing an inside straight in poker (this is the element of chance). Although a 10-year flood may occur on the average only once every 10 years, it is possible for several floods of this magnitude to occur in any one year, just as it is possible to throw two straight sixes with a die.

Precursor Events Many hazardous events are preceded by **precursor events.** For example, the surface of the ground may creep (move slowly) for a long period prior to an actual landslide. Often the rate of creep increases up to the final failure and landslide. Volcanoes sometimes swell or bulge before an eruption, and often a significant increase occurs in local seismic activity in the area surrounding the volcano. Foreshocks or anomalous (unusual) uplift may precede earthquakes. Precursor events help predict when and where an event is likely to happen. Landslide creep or swelling of a volcano may result in a warning being issued and people evacuated from a hazardous area.

Forecasting With some natural processes it is possible to **forecast** accurately when the event will arrive. Flooding of the Mississippi River, which occurs in the spring in response to snowmelt or very large regional storm systems, is fairly predictable, and we can sometimes forecast when the river will reach a particular flood stage. When hurricanes are spotted far out to sea and tracked toward the shore, we can forecast when and where they will likely strike land. Tsunamis, or seismic sea waves, generated by disturbance of ocean waters by earthquakes or submarine volcanoes, may also be forecast. The tsunami warning system has been fairly successful in the Pacific Basin, and in some instances the time of arrival of the waves has been forecast precisely.

Warning After a hazardous event has been predicted or a forecast has been made, the public must be warned. The flow of information leading to the **warning** of a possible disaster such as a large earthquake or flood should move along a path similar to that shown in Figure 4.4. The public does not always welcome such warnings, however, especially when the predicted event does not come to pass. In 1982, when geologists advised that a volcanic eruption near Mammoth Lakes, California, was quite likely, the advisory caused loss of tourist business and apprehension on the part of the residents. The eruption did not occur and the advisory was eventually lifted. In July 1986, a series of earthquakes occurred over a four-day period in the vicinity of Bishop, California, in the eastern Sierra Nevada, beginning with an earthquake of magnitude 3 and culminating in a damaging earthquake of magnitude 6.1. Investigators concluded there was a high probability a larger quake would occur in the vicinity in the near future and issued a warning. Local business owners, who feared the loss of summer tourism, felt that the warning was irresponsible; in fact, the predicted quake never materialized.

Incidents of this kind have led some people to conclude that scientific predictions are worthless and that advisory warnings should not be issued. Part of the problem is poor communication between the investigating scientists and reporters for the media (see *A Closer Look: Scientists, Hazards, and the Media*). Newspaper, television, and radio reports may fail to explain the evidence or the probabilistic nature of disaster prediction, leading the public to expect completely reliable statements as to what will happen. Although scientists are not yet able to predict volcanic eruptions and earthquakes accurately, it would seem that they have a responsibility to publicize their informed judgments. An informed public is better able to act responsibly than an uninformed public, even if the subject makes people un-



◀ **FIGURE 4.4** Possible flow path for issuance of a prediction or warning for a natural disaster.

comfortable. Ship captains, who depend on weather advisories and warnings of changing conditions, do not suggest that they would be better off not knowing about an impending storm, even though the storm might veer and miss the ship. Just as weather warnings have proved very useful for planning, official warnings of hazards such as earthquakes, landslides, and floods will also be useful to people making decisions about where they live, work, and travel.

Consider once more the prediction of a volcanic eruption in the Mammoth Lake area of California. The seismic data suggested to scientists that molten rock was moving toward the surface. In view of the high probability that the volcano would erupt and the possibility of loss of life if it did, it would have been irresponsible for scientists not to issue an advisory. Although the eruption did not occur, the warning led to the development of evacuation routes and consideration of disaster preparedness. This planning may prove very useful, for it is very likely that a volcanic eruption will occur in the Mammoth Lake area in the future. The most recent event occurred only 600 years ago! As a result of the prediction, the community is better informed than it was before and thus better able to deal with an eruption when it does occur.

A CLOSER LOOK Scientists, Hazards, and the Media

People today learn what is happening in the world by watching television, browsing the Web, listening to the radio, or reading newspapers and magazines. Reporters for the media are generally more interested in the impact of a particular event on people than in its scientific aspects. Even major volcanic eruptions or earthquakes in unpopulated areas may receive little media attention, whereas moderate or even small events in populated areas are reported in great detail. The news media want to sell stories, and what sells is spectacular events that affect people and property (3).

In a perfect world we would like to see good relations between scientists and the news media, but this lofty ideal may be difficult to achieve. Scientists tend to be conservative, critical people, afraid of being misquoted. They may perceive reporters as pushy and aggressive, or as willing to present half-truths while playing up differences of scientific opinion to embellish a story. Reporters, on the other hand, may perceive scientists as uncooperative and aloof, speaking an impenetrable jargon and unappreciative of the deadlines that reporters face (3). These statements about scientists and communicators are obviously stereotypic. Both groups have high ethical and professional standards; nevertheless, communication problems and conflicts of interest often occur.

Because scientists have an obligation to provide the public with information about natural hazards, it is good policy for a research team to pick one spokesperson to talk to the media so that the information is presented as consistently as possible. Suppose, for example, that scientists are studying a swarm of earthquakes near Los Angeles and there is speculation among them about the significance of the swarm. The development of several working hypotheses and future scenarios is the general rule for earth scientists working on a problem. However, when these scientists are dealing with the news media on a topic that concerns people's lives and property, it is better for them to report a consensus than a variety of opinions, or the public may be led to believe that they don't know what they are talking about. Their reports should be conservative evaluations of the evidence at hand, presented with as little jargon as possible. Reporters, for their part, should strive to provide their readers, viewers, or listeners with accurate information that the scientists have verified. Embarrassing scientists by misquoting them will only lead to more mistrust and poor communication between scientists and journalists.

Risk Assessment

Before rational people can discuss and consider adjustments to hazards, they must have a good idea of the risk that they face under various scenarios. The field of risk assessment is a rapidly growing one in the analysis of hazards, and its use and application should probably be expanded.

The **risk** of a particular event is defined as the product of the probability of that event occurring times the consequences should it occur (4). Consequences (damages to people, property, economic activity, public service, and so on) may be expressed in a variety of scales. If, for example, we are considering the risk from earthquake damage to a nuclear reactor, we may evaluate the consequences in terms of radiation released, which then can be related to damages to people and other living things. In any such assessment, it is important to calculate the risks for various possible events—in this example, for earthquakes of various magnitudes. A large event has a lower probability of occurring than does a small one, but its consequences are likely to be greater.

Determining *acceptable risk* is more complicated, for the risk that society or individuals are willing to take depends upon the situation. Driving an automobile is fairly risky, but most of us accept that risk as part of living in a modern world. On the other hand, acceptable risk from a nuclear power plant is very low because we consider almost any risk of radiation poisoning unacceptable. Nuclear power plants are controversial because many people perceive them as high-risk facilities. Even though the probability of an accident due to a geologic hazard, such as an earthquake, may be quite low, the consequences could be high, resulting in a relatively high risk.

A frequent problem of risk analysis is lack of reliable data for analyzing either the probability or the consequences of an event. It can be very difficult to assign probabilities to geologic events, such as earthquakes and volcanic eruptions, because the known chronology of past events is often very inadequate (4). Similarly, it may be very difficult to determine the consequences of an event or series of events. For example, if we are concerned with the consequences of releasing radiation into the environment, we need a lot of information about the local biology, geology, hydrology, and meteorology, all of which may be complex and difficult to analyze. Despite these limitations, risk analysis is a step in the right direction. As we learn more about determining the probability and consequences of a hazardous event, we should be able to provide the more reliable analyses necessary for decision making.

4.3 The Human Response to Hazards

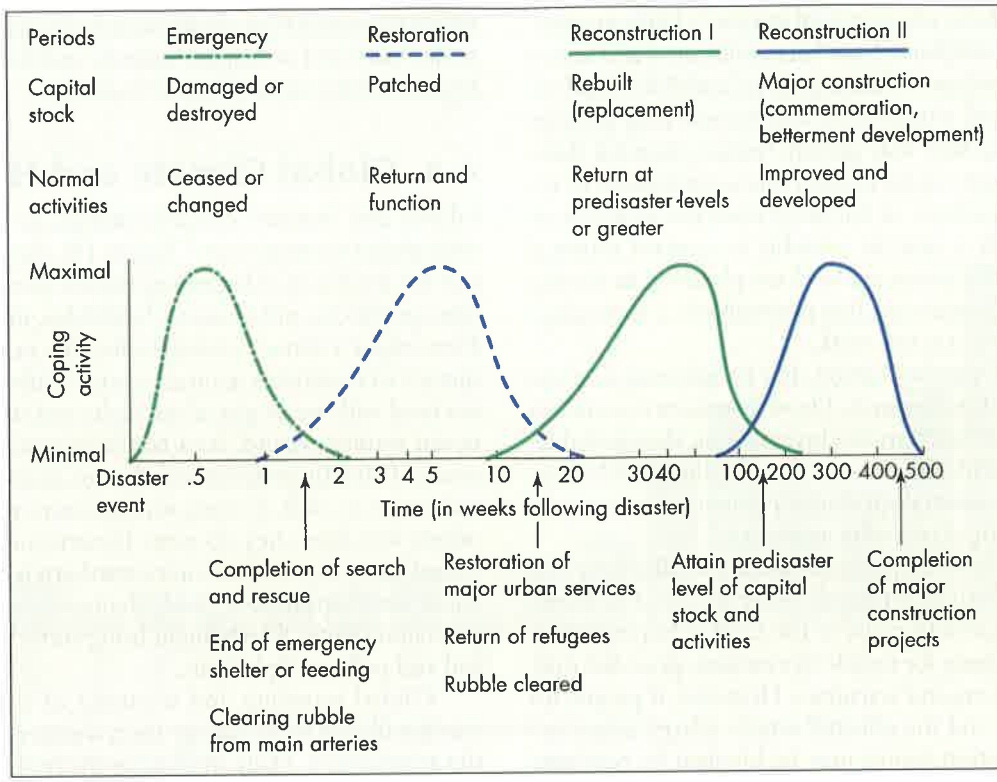
The ways in which we deal with hazards are too often primarily *reactive:* Following a disaster, we engage in search and rescue, fire fighting, and providing emergency food, water, and shelter. There is no denying that these activities reduce loss of life and property and need to be continued. However, the move to a higher level of hazard reduction will require increased efforts to *anticipate* disasters and their impact. Land-use planning to avoid hazardous locations, hazard-resistant construction, and hazard modification or control (such as flood control channels) are some of the adjustments that anticipate future disastrous events and may reduce our vulnerability to them (1).

Reactive Response: Impact of and Recovery from Disasters

The impact of a disaster upon a population may be either direct or indirect. *Direct effects* include people killed, injured, dislocated, or otherwise damaged by a particular event. *Indirect effects* are generally responses to the disaster. They include emotional distress, donation of money or goods, and the paying of taxes levied to finance the recovery. Direct effects have an impact on fewer individuals, whereas indirect effects have an impact on many more people (5,6).

The stages of recovery following a disaster are emergency work, restoration of services and communication lines, and reconstruction. Figure 4.5 shows an idealized model of recovery. This model can be applied to actual recovery activities following events such as the 1994 Northridge earthquake in the Los Angeles area. Restoration following the earthquake began almost immediately (roads were repaired, utilities restored, etc.) in response to an influx of dollars from federal programs, insurance companies, and other sources in the first few weeks and months after the earthquake. The damaged areas moved quickly from the restoration phase to the Reconstruction I stage (which will last beyond the year 2000).

As we move into the Reconstruction II period following the Northridge earthquake, it is important to remember lessons from two past disasters: The 1964 earthquake that struck Anchorage, Alaska, and the flash flood that devastated Rapid City, South Dakota, in 1972. Restoration following the earthquake in Anchorage began almost immediately in response to a tremendous influx of dollars from federal programs, insurance companies, and other sources approximately one month after the earthquake. As a result, reconstruction was a hectic process, with everyone trying to obtain as much of the available funds as possible. In Rapid City, the restoration did not peak until approximately 10 weeks after the flood, and the community took time to carefully think through the best alternatives. As a result, Rapid City today has an entirely different land use on the floodplain, and the flood hazard is much reduced. Conversely, in Anchorage the rapid restoration and reconstruction were accompanied by little land-use planning. Apartments and other buildings were hurriedly constructed across areas that had suffered ground rupture and were simply filled in and regraded. In ignoring the potential benefits of careful land-use planning, Anchorage is vulnerable to the same type of earthquake that struck in 1964. In Rapid City, the floodplain is now a green belt with golf courses and other such activities—a change that has reduced the flood hazard (2,5,6).



▲ **FIGURE 4.5** Generalized model of recovery following a disaster. (*From Kates and Pijawka*, 1977. *Reconstruction following disaster.* In From rubble to monument: The pace of reconstruction, *eds.* J. E. Haas, R. W. Kates, and M. J. Bowden. *Cambridge, MA: MIT Press*)

In the Northridge case, the effects of the earthquake on highway overpasses and bridges, buildings, and other structures are being carefully evaluated to determine how improved engineering standards for construction of new structures or strengthening of older structures might be implemented during the Reconstruction II period (see Figure 4.5). Future moderate-to-large earthquakes are certain to occur again in the Los Angeles area. Therefore, we need to continue efforts in the area of earthquake hazard reduction.

Anticipatory Response: Avoiding and Adjusting to Hazards

The options we choose, individually or as a society, for avoiding or minimizing the impacts of disasters depend in part on our hazard perception. A good deal of work has been done in recent years to try to understand how people perceive various natural hazards. This is important because the success of hazard reduction programs depends on the attitudes of the people likely to be affected by the hazard. Although there may be an adequate perception of a hazard at the institutional level, this may not filter down to the general population. This is particularly true for events that occur infrequently; people are more aware of situations such as brush or forest fires (Figure 4.6) that may occur every few years. There may even be institutionalized as well as local ordinances to control damages resulting from these events. For example, homes in some areas of southern California are roofed with shingles that do not burn readily and sometimes even have sprinkler systems, and the lots are often cleared of brush. Such safety measures are often noticeable during the rebuilding phase following a fire.

▲ **FIGURE 4.6** Wildfire in October 1991 devastated this Oakland, California neighborhood. (*Tom Benoit/Tony Stone Images*)

One of the most environmentally sound adjustments to hazards involves **land-use planning.** That is, people can avoid building on floodplains, in areas where there are active landslides, or in places where coastal erosion is likely to occur. In many cities, floodplains have been delineated and zoned for a particular land use. With respect to landslides, legal requirements for soil engineering and engineering geology studies at building sites may greatly reduce potential damages. Damages from coastal erosion can be minimized by requiring adequate setback of buildings from the shoreline or seacliff. Although it may be possible to control physical processes in specific instances, land-use planning to accommodate natural processes is often preferable to a technological fix that may or may not work.

Insurance is another option that people may exercise in dealing with natural hazards. Flood insurance is common in many areas, and earthquake insurance is also available. However, because of large losses following the 1994 Northridge earthquake, several insurance companies announced they would no longer offer the insurance.

Evacuation is an important option or adjustment to the hurricane hazard in the states along the Gulf of Mexico and along the eastern coast of the United States. Often there is sufficient time for people to evacuate, provided they heed the predictions and warnings. However, if people do not react quickly and the affected area is a large urban region, then evacuation routes may be blocked by residents leaving in a last-minute panic. Successful evacuation from volcanic eruptions is mentioned in Chapter 8.

Disaster preparedness is an option that individuals, families, cities, states, or even entire nations can implement. Of particular importance here is training individuals and institutions to handle large numbers of injured people or people attempting to evacuate an area after a warning is issued.

Attempts at *artificial control of natural processes* such as landslides, floods, and lava flows have had mixed success. Even the best-designed artificial structures cannot be expected to always defend against an extreme event. Retaining walls and other structures to defend slopes from failure by landslide have generally been successful when well designed. Even the casual observer has probably noticed the variety of such structures along highways and urban land in hilly areas. Structures to defend slopes have limited impact on the environment and are necessary where construction demands that artificial cuts be excavated or where unstable slopes impinge on human structures. Common methods of flood control are channelization and construction of dams and levees. Unfortunately, flood control projects tend to provide floodplain residents with a false sense of security because no method can be expected to protect people and their property absolutely from high-magnitude floods. We will return to this discussion in Chapter 5.

An option that all too often is chosen is simply bearing the loss caused by a natural disaster. Many people are optimistic about their chances of making it through any sort of disaster and therefore will take little action in their own defense. This is particularly true for those hazards—such as volcanic eruptions and earthquakes—that occur only rarely in a particular area. Regardless of the strategy we choose either to minimize or avoid hazards, it is imperative that we understand and anticipate hazards and their physical, biological, economic, and social impacts.

4.4 Global Climate and Hazards

Global and regional climatic change, possibly associated with global warming (see Chapter 16), may significantly affect the incidence of hazardous natural events, such as storm damage (floods and erosion), landslides, drought, and fires. How might a climatic change affect the magnitude and frequency of disastrous natural events? With global warming, sea level will rise as glacial ice melts and thermally warmed ocean waters expand. As a result, coastal erosion will increase. Climatic patterns will change, causing food production areas to shift as some receive more precipitation and others less than they do now. Deserts and semiarid areas would likely expand, and more northern latitudes could become more productive. Such changes could lead to global population shifts, which might bring about wars or major social and political upheavals.

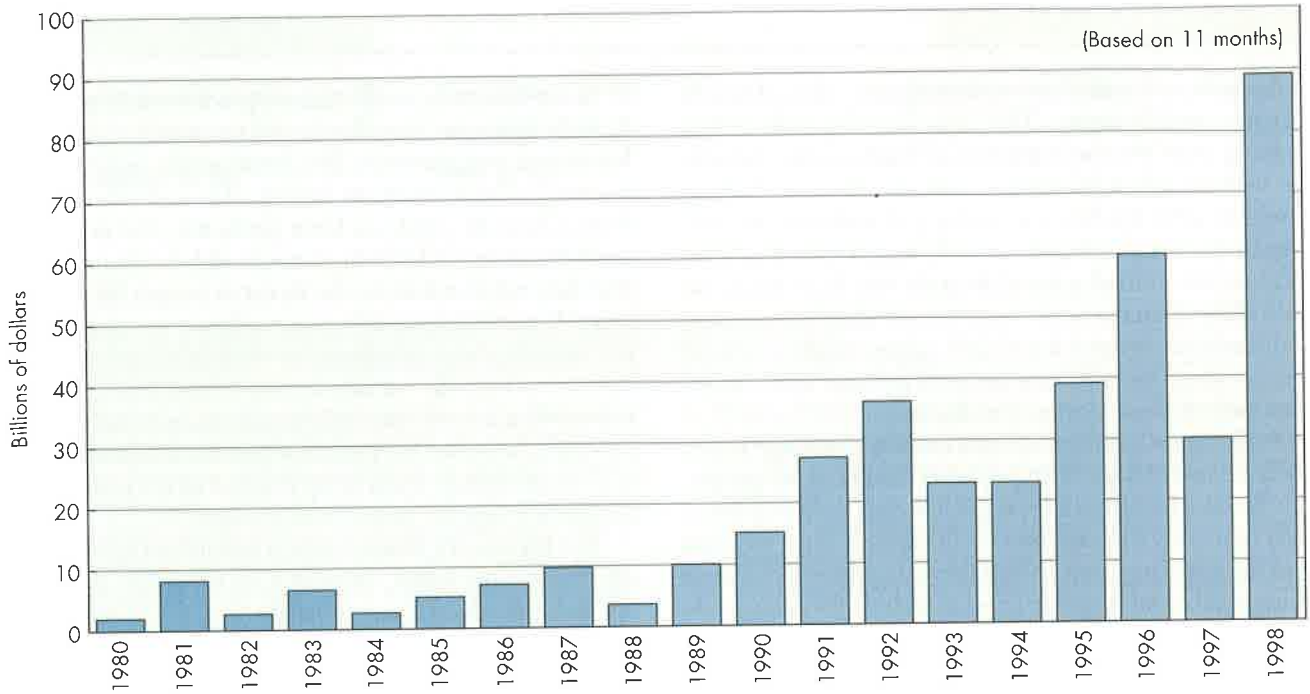
Global warming and warming of the oceans of the world will feed more energy from warmer ocean water into the atmosphere, likely increasing the frequency and severity of hazardous weather-related processes, including thunderstorms (with tornadoes) and hurricanes. In fact, this may already be happening, because 1998 set a new record for economic losses from weather-related disasters, causing at least $89 billion in economic losses worldwide. This represents a 48 percent increase over the previous record of $60 billion set in 1996. In fact, losses from storms, floods, fires, and droughts in 1998, the warmest year on record, are greater than the $55 billion in losses for the entire decade of the 1980s (Figure 4.7). Global impact on people from weather-related disasters in 1998 was catastrophic, killing approximately 32,000 people while displacing another 300 million people from their homes (7).

4.5 Population Increase, Land-Use Change, and Natural Hazards

Population Increase and Hazardous Events

Population increase is a major environmental problem. As our population continues to increase, putting greater demands on our land and resources, the need for planning to minimize losses from natural disasters also increases. Specifically, an increase in population puts a greater number of people at risk from a natural event and forces more people to settle in hazardous areas, creating additional risks. The risks of both high population density and living in a danger zone are dramatically illustrated by the loss of thousands of lives in Mexico and Colombia in 1985.

Mexico City is the center of the world's most populous urban area. Approximately 23 million people are concentrated in an area of about 2300 km^2, and about



▲ **FIGURE 4.7** Worldwide economic losses from weather-related natural hazards (1980–1998). (*Source: World Watch Institute*, 1998. *Vital Signs Brief* 98-5)

one-third of the families (which average five members) live in a single room. The city is built on ancient lake beds, which accentuate earthquake shaking, and parts of the city have been sinking at the rate of a few centimeters per year, owing in part to groundwater withdrawal. The subsidence has not been uniform, so the buildings tilt and are even more vulnerable to the shaking of earthquakes (8). In September 1985, Mexico endured a magnitude 7.8 earthquake that killed about 10,000 people in Mexico City alone.

When the Colombian volcano Nevado del Ruiz erupted in 1845, a mudflow roared down the east slope of the mountain, killing about 1000 people. Deposits from that event produced rich soils in the Lagunilla River valley, and an agricultural center developed there. The town that the area supported was known as Armero, and by 1985 it had a population of about 22,500. On November 13, 1985, another mudflow associated with a volcanic eruption buried Armero, leaving about 21,000 people dead or missing (see Figure 8.22). A matter of 140 years multiplied the mudflow toll more than 20 times because of population increase. Ironically, the area was decimated by the same event that earlier produced productive soils, stimulating development and population growth (9). The real tragedy is that the mudflow was predicted and evacuation could have saved thousands of lives (3).

Land-Use Change and Hazardous Events

Two of the deadliest catastrophes resulting from natural hazards in 1998 were the flooding of the Yangtze River in China and Hurricane Mitch, which devastated Central America. Hurricane Mitch caused approximately 11,000 deaths, while the floods in the Yangtze River resulted in nearly 4,000 deaths. It has been speculated that damages in Central America and China from these events were particularly severe because of land-use changes that had occurred. For example, Honduras has lost nearly one-half of its forests, and a 11,000-km^2 fire occurred in the region prior to the hurricane. As a result of deforestation and the fire, hillsides that were stripped of vegetation washed away, and with them went farms, homes, roads, and bridges. In central China the story is much the same as the Yangtze River basin has lost about 85 percent of its forest as a result of timber harvesting and conversion of land to agriculture in recent times. As a result of the land-use changes in China, flooding of the Yangtze River is probably much more common than it was previously (7).

The hazardous events that caused catastrophes in 1998 in Central America, China, and other parts of the world may be an early warning sign of things to come. It is apparent that human activities are likely increasing the impacts of natural disasters. In recognition of this, China has banned timber harvesting in the upper Yangtze River basin, unwise floodplain land uses have been prohibited, and several billion dollars have been allocated for reforestation. The lesson being learned is that if we wish to minimize damages from natural hazards in the future, we need to consider land rehabilitation with the goal of achieving sustainable development based on restoration and maintenance of healthy ecosystems (7). It will be difficult, given pressures of human population growth in many parts of the world. This emphasizes the need to control human population growth if we are to solve pressing environmental problems and reach our goal of sustaining our environment.

SUMMARY

Our discussion of natural processes suggests a view of nature as dynamic and changing. This understanding tells us that we cannot view our environment as fixed in time. A landscape without natural hazards would also have less variety; it would be safer but less interesting and probably less aesthetically pleasing. The jury is still out on how much we should try to control natural hazards and how much we should allow them to occur. However, we should remember that disturbance is natural and that management of natural resources must include management for and with disturbances such as fires, storms, and floods.

A fundamental principle of environmental geology is that there have always been earth processes dangerous to people. These become hazards when people live close to the source of danger or modify a natural process or landscape in a way that makes it more dangerous. Natural events that will continue to cause deaths and property damage include flooding, landslides, earthquakes, volcanic activity, wind, expansive soils, drought, fire, and coastal erosion. The frequency of a hazardous event is generally inversely related to its magnitude; its impact on people depends on its frequency and magnitude as well as such diverse factors as climate, geology, vegetation, and human use of the land. The same natural events that create disasters may also bring about benefits, as when river flooding or a volcanic eruption supplies nutrients to soils.

The events causing the greatest number of deaths in the United States are tornadoes and windstorms, lightning, floods, and hurricanes, although a single great earthquake can take a very large toll. Floods, landslides, expansive soils, and frost cause the greatest property damage. Events most likely to produce a catastrophe (a disaster requiring a long, involved recovery) are floods, hurricanes, tornadoes, earthquakes, volcanic eruptions, and fires. Land-use changes, urbanization, and population increase are causing damage from most hazards to increase in the United States, but better prediction and warning are causing deaths from many hazardous processes to decrease.

Some disastrous events can be predicted fairly accurately, including some river floods and the arrival at the coast of hurricanes and tsunamis. Precursor events sometimes give warning of such events as earthquakes and volcanic eruptions. Once an event has been predicted, this information must be made available to planners and decision makers so that they might minimize the threat to human life and property. Of particular significance are how a warning is issued and how scientists communicate with the media and public. For many hazards we cannot determine when a specific event will occur; we can only predict the probability of occurrence, based on the record of past occurrences. The risk associated with an event is the product of the probability of occurrence and the likely consequences.

The impact of a disaster upon a population includes direct effects—people killed, dislocated, or otherwise damaged—and indirect effects—emotional distress, donation of money or goods, and paying taxes to finance recovery. Recovery often has several stages, including emergency work, restoration of services and communication, and reconstruction.

The options that individuals or societies choose for avoiding or adjusting to natural hazards depend in part on hazard perception, which is highest for common events. Options include land-use planning, insurance, evacuation, disaster preparedness, artificial control of natural processes, and bearing the loss. Attempts to control natural processes artificially have had mixed success and usually cannot be expected to defend against extreme events. Regardless of the approach we choose, we must increase our understanding of hazards and do a better job of anticipating them.

As the world's population increases and we continue to modify our environment through changes such as urbanization and deforestation, more people will live on marginal lands and in more hazardous locations. Therefore, as population increases, better planning at all levels will be necessary if we are to minimize losses from natural hazards.

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KEY TERMS

magnitude-frequency concept (p. 88)
catastrophe (p. 89)
precursor events (p. 90)
forecasting (p. 90)
warning (p. 90)
risk (p. 92)
disaster preparedness (p. 94)

SOME QUESTIONS TO THINK ABOUT

1. Make a list of all the natural processes that are hazardous to people and property in the region where you live. What adjustments have you and the community in general made to lessen the impacts of these hazards? Could more be done? What? Which alternatives are environmentally preferable?
2. Assume that in the future we will be able to predict with a given probability when and where a large, damaging earthquake will occur, as we do today for hurricanes. If the probability that the earthquake will occur on a given date is quite low, say 10 percent, should the general public be informed of the forecast? Should we wait until a 50 percent confidence or even a 90 percent confidence is assured? Does the length of time between the forecast and the event have any bearing on your answers?
3. Find a friend, and one of you take the role of a scientist and another a news reporter. Assume the news reporter is interviewing the scientist about the nature and extent of hazardous processes in your town. Following the interview, jot down some of your thoughts concerning ways in which scientists communicate with newspeople. Are there any conflicts?
4. Develop a plan for your community to evaluate the risk of flooding. How would you go about determining an acceptable risk?
5. Do you agree or disagree that land-use change and population increase enhances risk from natural processes? Develop a hypothesis and discuss how it might be tested.