Natural Hazards and Disasters

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Hyndman.

Flooding during Hurricane Ike in 2008 undermined tall posts supporting houses on the barrier island east of Galveston, Texas, toppling them into the surf.

Those who cannot remember the past are condemned to repeat it.

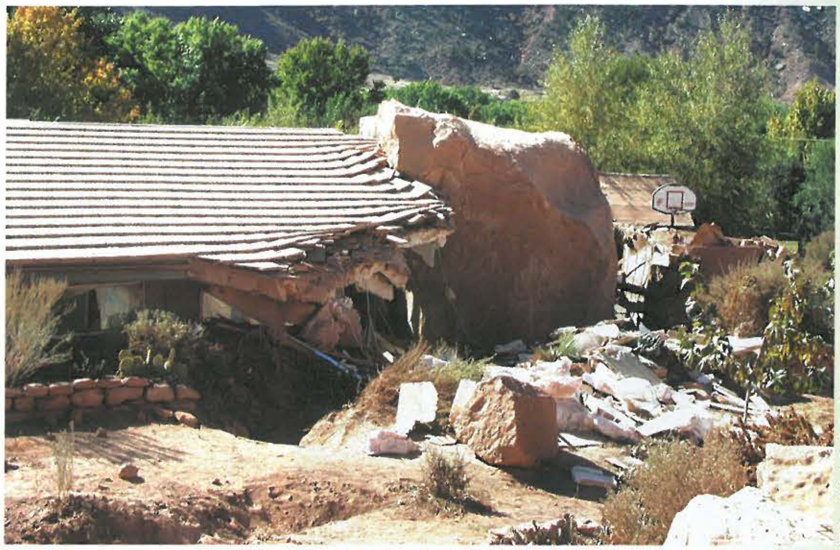
—George Santayana (Spanish philosopher), 1905

Living in Harm's Way

Why would people choose to put their lives and property at risk? Large numbers of people around the world live and work in notoriously dangerous places—near volcanoes, in floodplains, or on active fault lines. Some are ignorant of potential disasters, but others even rebuild homes destroyed in previous disasters. Sometimes the reasons are cultural or economic. Because volcanic ash degrades into richly productive soil, the areas around volcanoes make good farmland. Large floodplains attract people because they provide good agricultural soil, inexpensive land, and natural transportation corridors. Some people live in a hazardous area because of their job or because they find the place appealing. For understandable reasons, such people live in the wrong places. Hopefully they recognize the hazards and understand the processes involved so they can minimize their risk.

But people also crowd into dangerous areas for frivolous reasons. They build homes at the bases or tops of large cliffs for scenic views, not realizing that big sections can give way in

FIGURE 1-1 THE UNEXPECTED



This four-year-old house near Zion National Park in southern Utah was built near the base of a steep rocky slope capped by a sandstone cliff. Early one morning in October 2001, the owner awoke with a start as a giant boulder 4.5 meters (almost 15 feet) across crashed into his living room and bedroom, narrowly missing his head.

landslides or rockfalls (**FIGURE 1-1**). They long to live along edges of sea bluffs where they can enjoy ocean views, or they want to live on the beach to experience the ocean more intimately. Others build beside picturesque, soothing rivers. Far too many people build houses in the woods because they enjoy the seclusion and scenery of this natural setting.

Some experts concerned with natural catastrophes say these people have chosen to live in "idiot zones." But people don't usually reside in hazardous areas knowingly—they generally don't understand or recognize the hazards. However, they might as well choose to park their cars on a rarely-used railroad track. Trains don't come frequently, but the next one might come any minute.

Catastrophic natural hazards are much harder to avoid than passing freight trains; we may not recognize the signs of imminent catastrophes because these events are infrequent. So decades or centuries may pass between eruptions of a large volcano that most people forget it is active. Many people live so long on a valley floor without seeing a big flood that they forget it is a floodplain. The great disaster of a century ago is long forgotten, so folks move into the path of a calamity that will occur on some unknowable future date. The hazardous event may not arrive today or tomorrow, but it is just a matter of time.

Catastrophes in Nature

Everyday geologic processes, like erosion, have produced large effects over the course of Earth's vast history, carving out valleys or changing the shape of coastlines. While some processes operate slowly and gradually, infrequent catastrophic events have sudden and major impacts. For instance, streams that run clear most of the year are muddy during a few high water days or weeks, when they carry most of their annual load of sediment. That sediment reflects a short and intense erosion period.

FIGURE 1-2 **A LOOMING CATASTROPHE**

Donald Hyndman.

Orting Washington, with spectacular views of Mount Rainier, is built on a giant, ancient mudflow from the volcano. If mudflows happened in the past, they almost certainly will happen again.

FIGURE 1-3 **A DISASTER TAKES A HIGH TOLL**

UN Development Program.

The Haiti earthquake of January 12, 2010, killed more than 222,000, mostly in concrete and cinder block buildings with little or no reinforcing steel. Searchers dig for survivors.

Major floods occurring once every ten or twenty years do far more damage and move more material than all of the intervening floods put together. Soil moves slowly downslope by creep, but occasionally a huge part of a slope may slide. Mountains grow higher, sometimes slowly, but more commonly by sudden movements. During an earthquake, a mountain can abruptly rise several meters above an adjacent valley.

Some natural events involve disruption of a temporary *equilibrium*, or balance, between opposing influences. Unstable slopes, for example, may hang precariously for thousands of years, held there by friction along a slip surface until some small perturbation, such as water soaking in from a large rainstorm, sets them loose. Similarly, the opposite sides of a fault may stick until continuing stress finally tears them loose, triggering an earthquake. A bulge may form on a volcano as molten magma slowly rises into it; then it collapses as the volcano erupts. The behavior of these natural systems is somewhat analogous to a piece of fabric or plastic wrap that remains intact as it stretches until it suddenly tears.

People watching Earth processes move at their normal and unexciting pace rarely pause to imagine what might happen if that slow pace were suddenly punctuated by a major event. The fisherman enjoying a quiet afternoon trout fishing in a small stream can hardly imagine how a 100-year flood might transform the scene. Someone gazing at a serene, snow-covered mountain can hardly imagine it erupting in an explosive blast of hot ash (**FIGURE 1-2**) followed by destructive mudflows racing down its flanks. Large or even gigantic events are a part of nature. Such abrupt events produce large results that can be disastrous if they affect people.

Human Impact of Natural Disasters

When a natural process poses a threat to human life or property, we call it a **natural hazard**. Many geologic processes are potentially hazardous. For example, streams flood, as part of their natural process, and become a hazard to those living nearby. A hazard is a **natural disaster** when the event causes significant damage to life or property. A moderate flood that spills over a floodplain every few years does not often wreak havoc, but when a major flood strikes, it may lead to a disaster that kills or displaces many people. When a natural event kills or injures large numbers of people or causes extensive property damage, it is called a **catastrophe**.

The potential impact of a natural disaster is related not only to event size but also to its effect on the public. A natural event in a thinly populated area can hardly pose a major hazard. For example, the magnitude 7.6 earthquake that struck the southwest corner of New Zealand on July 15, 2009, was severe but posed little threat because it happened in a region with few people or buildings. However, the magnitude 7.6 Kashmir earthquake occurred in heavily populated valleys of the southern Himalayas and killed more than 80,000 people, and the much smaller January 12, 2010, magnitude 7.0 earthquake in Haiti killed more than 222,000 (**FIGURE 1-3**). The May 2, 2008, cyclone in Myanmar killed an estimated 138,000 in a mostly rural area. By contrast, super typhoon Choi-Wan, a monstrous category 5 storm that passed directly over the Northern Marianas Islands south of Japan on September 15, 2009, resulted in no deaths because few people live there. The eruption of Mount St. Helens in 1980 caused few fatalities and remarkably little property damage simply because the area surrounding the mountain is sparsely populated. On the other hand, a similar eruption of Vesuvius, on the outskirts of Naples, Italy, could kill hundreds of thousands of people and cause property damage beyond reckoning.

People often associate natural hazard deaths with dramatic events, such as large earthquakes, volcanic eruptions, floods, hurricanes, or tornadoes. However, some of the most dramatic natural hazards occur infrequently or in restricted areas, so they cause fewer deaths than more common and less dramatic hazards. **FIGURE 1-4** shows the approximate proportions of fatalities caused by typical natural hazards in the United States.

In the United States, heat and drought account for the largest numbers of deaths. In fact, there were more U.S. deaths from heat waves between 1997 and 2008 than from any other type of natural hazard. In addition to heat stress, summer heat wave fatalities can result from dehydration and other factors; the very young, the very old, and the poor are affected the most. The same populations are vulnerable during winter weather, the third most deadly hazard in the U.S. Winter deaths often involve hypothermia, but some surveys include, for example, auto accidents caused by icy roads.

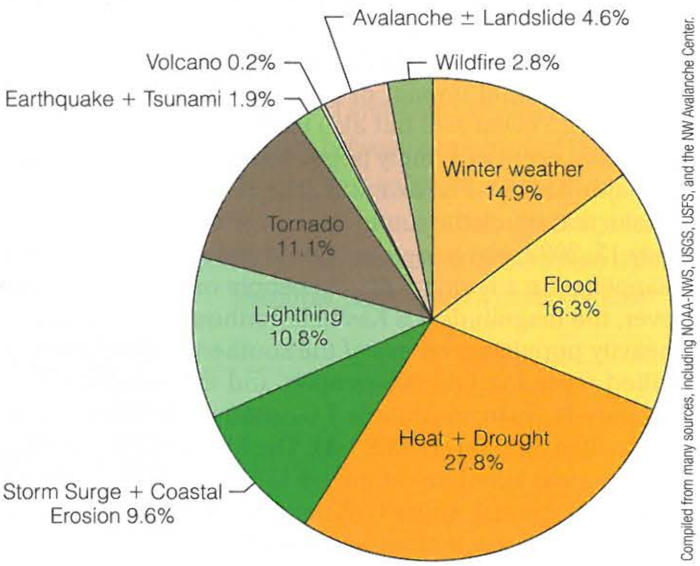
Flooding is the second most deadly hazard in the U.S., accounting for 16 percent of fatalities between 1986 and 2008. Fatalities from flooding can result from hurricane-driven floods; some surveys place them in the hurricane category rather than floods.

The number of deaths from a given hazard can vary significantly from year to year due to rare, major events. For example, there were about 1,800 hurricane-related deaths in 2005 when Hurricane Katrina struck, compared with zero in other years. The rate of fatalities can also change over time as a result of safety measures or trends in leisure activities. Lightning deaths were once amongst the most common hazard-related causes of death, but associated casualties have declined by a factor of five from 1940–1959 compared with 1989–2009, due in part to satellite radar and better weather forecasting. In contrast, avalanche deaths have increased by a factor of five from 1952–1971 compared with 1989–2008, a change that seems to be associated with snowmobile use and skiing in mountain terrains.

Some natural hazards can cause serious physical damage to land or manmade structures, some are deadly for people, and others are destructive to both. The type of damage sustained as a result of a natural disaster also depends on the economic development of the area where it occurs. In developing countries, there are increasing numbers of deaths from natural disasters, whereas in developed countries, there are typically greater economic losses. Developing countries show dramatic increases in populations relegated to marginal and hazardous land on steep slopes and near rivers. They have less ability to evacuate as hazards loom. Developed countries show lower population growth, forewarning is more immediate, and people can easily move.

The average annual cost of natural hazards has increased dramatically over the last several decades (**FIGURE 1-5**). This is due in part to the increase in world population overall, but it is also a function of human migration to more hazardous areas. Overall losses have increased even faster than population growth. Population increases in urban and coastal settings result in more people occupying land that is subject to major natural events. In effect, people place themselves in the path of unusual, sometimes catastrophic events. Economic centers of society are increasingly concentrated in larger urban areas that tend to expand into regions previously considered undesirable, including those with greater exposure to natural hazards.

FIGURE 1-4 HAZARD-RELATED DEATHS



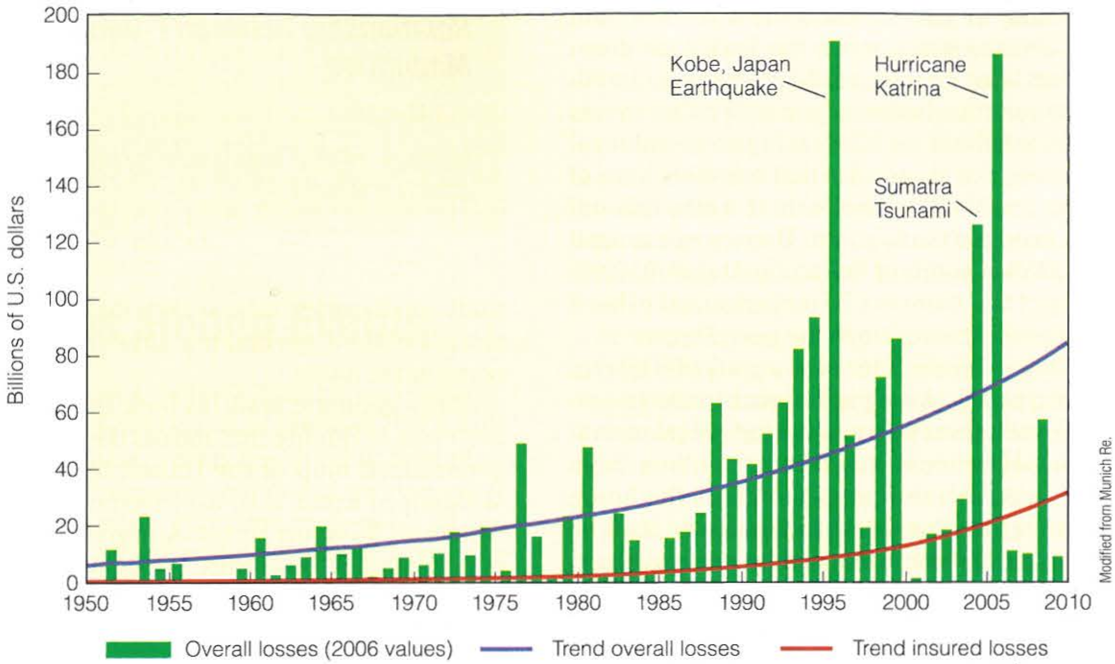
Approximate percentages of U.S. fatalities due to different groups of natural hazards from 1986 to 2008, when such data are readily available. For hazardous events that are rare or highly variable from year to year (earthquakes and tsunami, volcanic eruptions, and hurricanes), a 69-year record from 1940–2008 was used.

Predicting Catastrophe

A catastrophic natural event is unstoppable, so the best way to avoid it is to predict its occurrence and get out of the way. Unfortunately, for those who would predict the occurrence of a natural disaster on a particular date, the result is most often dejection. So far, there have been few well-documented cases of accurate prediction, and even the ones on record may have involved luck more than science. Use of the same techniques in similar circumstances has resulted in false alarms and failure to correctly predict disaster.

Many people have sought to find predictable cycles in natural events. Natural events that occur at predictable intervals are called **cyclic events**. However, even most recurrent events are generally not really cyclic; too many variables control their behavior. Even with cyclic events, overlapping cycles make resultant extremes noncyclic, which affects the predictability of an event. So far as

FIGURE 1-5 INCREASING COSTS OF NATURAL HAZARDS



The cost of natural hazards is increasing worldwide, partly because world population doubled from 3 billion to 6 billion in only 40 years, from 1959 to 1999. By 2009 it reached 6.8 billion.

anyone can tell, most episodes, large and small, occur at seemingly random and essentially unpredictable intervals. The calendar does not predict them.

Nevertheless, scientists who make it their business to understand natural disasters can provide some guidance to people at risk. They cannot predict exactly when an event will occur. However, based on past experience, they can often **forecast** the occurrence of a hazardous event in a certain area within decades with an approximate percentage probability. They can forecast that there will be a large earthquake in the San Francisco Bay region over the next several decades, or that Mount Shasta will likely erupt sometime in the next few centuries. In many cases, their advice can greatly reduce the danger to lives and property.

Ask a stockbroker where the market is going, and you will probably hear that it will continue to do what it has done during recent weeks. Ask a scientist to forecast an event, and he or she will probably look to the geologically recent past and forecast more of the same; in other words *the past is the key to the future*. Most predictions of any kind are based on linear projections of past experience. However, we must be careful to look at a long enough sample of the past to see prospects for the future. Many people lose money in the stock market because *short-term* past experience is not always a good indicator of what will happen in the future.

Statistical predictions are simply a refinement of past recorded experiences. They are typically expressed as **recurrence intervals** that relate to the probability that a natural event of a particular size will happen–within a certain period of time. For example, the past history of a fault may indicate that it is likely to produce an earthquake of a certain size once every hundred years on average.

A recurrence interval is not, however, a fixed schedule for events. Recurrence intervals can tell us that a 50-year flood is likely to happen sometime in the next several decades but not that such floods occur at intervals of 50 years. Many people do not realize the inherent danger of an unusual occurrence, or they believe that they will not be affected in their lifetimes because such events occur infrequently. That inference often incorrectly assumes that the probability of another severe event is lower for a considerable length of time after a major event. In fact, even if a 50-year flood occurred last year, that does not indicate that there will not be another one this year or next or for the next ten years.

To understand why this is the case, take a minute to review probabilities. Flip a coin, and the chance that it will come up heads is 50 percent. Flip it again, and the chance is again 50 percent. If it comes up heads five times in a row, the next flip still has a 50 percent chance of coming up heads. So it goes with floods and many other kinds of apparently random natural events. The chance that someone's favorite fishing stream will stage a 50-year flood this year and every year is 1 in 50, regardless of what it may have done during the last few years.

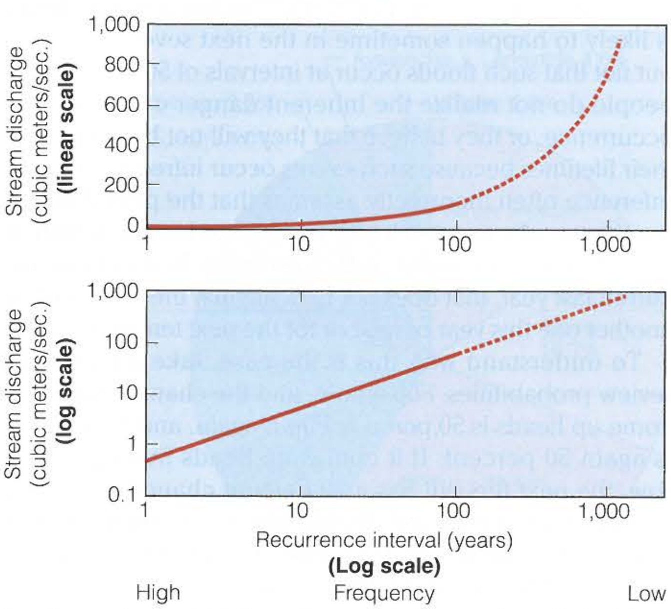
As an example of both the usefulness and the limitations of recurrence intervals, consider the case of Tokyo. This enormous city is subject to devastating earthquakes that for more than 500 years came at intervals of close to 70 years.

The last major earthquake ravaged Tokyo in 1923, so everyone involved awaited 1993 with considerable consternation. The risk steadily increased during those years as both the population and the strain across the fault zone grew. More than 15 years later, no large earthquake has occurred. Obviously, the recurrence interval does not predict events at equal intervals, in spite of the 500-year Japanese historical record. Nonetheless, the knowledge that scientists have of the pattern of occurrences here helps them assess risk and prepare for the eventual earthquake. There was a magnitude 7.1 event 325 km south of Tokyo on August 9, 2009, and experts project that there is a 70 percent chance that a major quake will strike that region in the next 30 years.

To estimate the recurrence interval of a particular kind of natural event, we typically plot a graph of each event size versus the time interval between sequential individual events. Such plots often make curved lines that cannot be reliably extrapolated to larger events that might lurk in the future (**FIGURE 1-6**). Plotting the same data on a logarithmic scale often leads to a straight-line graph that can be extrapolated to values larger than those in the historical record. Whether the extrapolation produces a reliable result is another question.

The probability of the occurrence of an event is related to the magnitude of the event. We see huge numbers of small events, many fewer large events, and only a rare giant event (**By the Numbers 1-1:** Relationship between Frequency and Magnitude). The infrequent occurrence of giant events means it is hard to study them, but it is often rewarding to study small events because they may well be smaller-scale models of their uncommon larger counterparts that may occur in the future.

FIGURE 1-6 RECURRENCE INTERVAL



If major events are plotted on a linear scale (top graph, vertical axis), the results often fall along a curve that cannot be extrapolated to larger possible future events. If the same events are plotted on a logarithmic scale (bottom graph), the results often fall along a straight line that can be projected to possible larger events.

By the Numbers 1-1

Relationship between Frequency and Magnitude

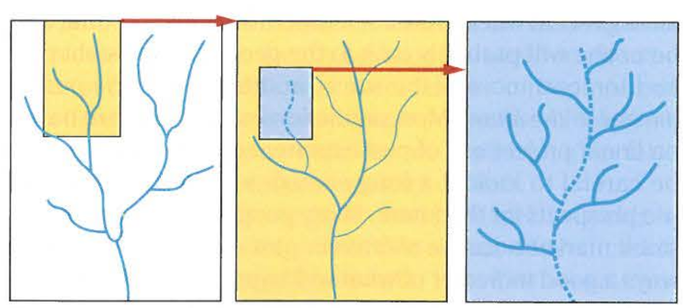
$$M \propto 1/f$$

Magnitude (M) of an event is inversely proportional to frequency (f) of the type of event.

Many geologic features look the same regardless of their size, a quality that makes them **fractal**. A broadly generalized map of the United States might show the Mississippi River with no tributaries smaller than the Ohio and Missouri rivers. A more detailed map shows many smaller tributaries. An even more detailed map shows still more. The number of tributaries depends on the scale of the map, but the general branching pattern looks *similar across a wide range of scales* (**FIGURE 1-7**). Patterns apparent on a small scale quite commonly resemble patterns that exist on much larger scales that cannot be easily perceived. This means that small events may provide insight into huge ones that occurred in the distant past but are larger than any seen in historical time; we may find evidence of these big events if we search. The scale of some natural catastrophes that have affected the Earth, and will do so again, is almost too large to fathom. Examples include catastrophic failure of the flanks of oceanic volcanoes or the impact of large asteroids. For these, reality is more awesome than fiction. Yet each is so well documented in the geologic record that we need to be aware of the potential for such extreme events in the future.

It is impossible in our current state of knowledge to predict most natural events, even if we understand in a general way what controls them. The problem of avoiding

FIGURE 1-7 THE BRANCHING OF STREAMS IS FRACTAL



The general style of a branching stream looks similar regardless of scale—from a less-detailed map on the left to the most-detailed map on the right.

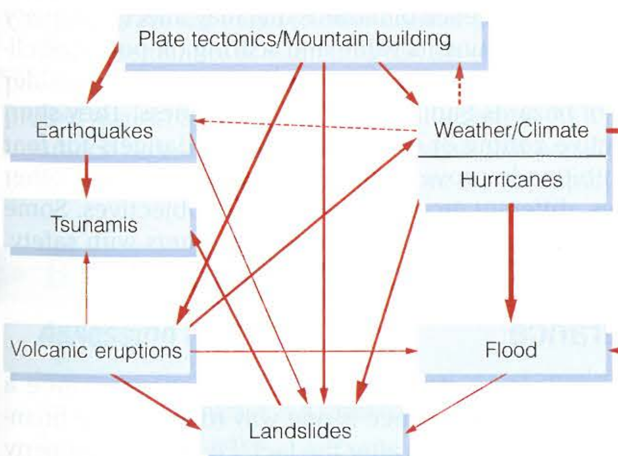
natural disasters is like the problem drivers face in avoiding collisions with trains. They can do nothing to prevent trains, so they must look and listen. We have no way of knowing how firm the natural restraints on a landslide, fault, or volcano may be. We also do not generally know what changes are occurring at depth. But we can be confident that the landslide or fault will eventually move or that the volcano will erupt. And we can reasonably understand what those events will involve when they finally happen.

Relationships among Events

Although randomness is a factor in forecasting disasters, not all natural events occur quite as randomly as floods or tosses of a coin. Some events are directly related to others—formed as a direct consequence of another event (**FIGURE 1-8**). For example, the slow movement of the huge outer layers of the Earth colliding or sliding past one another clearly explains the driving forces behind volcanic eruptions and earthquakes. Heavy or prolonged rainfall can cause a flood or a landslide. But are some events unrelated? Could any of the arrows in Figure 1-8 be reversed? Given all of the interlocking possibilities, the variability, and the uncertainties, we could call this figure a "chaos net" for natural hazards.

Past events can also create a contingency that influences future events. It is certainly true, for example, that sudden movement on a fault causes an earthquake. But the same movement also changes the stress on other parts of the fault and probably on other faults in the region, so the next earthquake will likely differ considerably from the last. Similar complex relationships arise with many other types of destructive natural events.

FIGURE 1-8 INTERACTIONS AMONG NATURAL HAZARDS



The bolder arrows in this flowchart indicate stronger influences. Can you think of others?

Some processes result in still more rapid changes—a *cascading* or *domino effect*. For example, global warming causes more rapid melting of Arctic sea ice. The resulting darker sea water absorbs more of the sun's energy than the white ice, and in turn, this causes even more sea ice melting. Similarly, global warming causes faster melting of the Greenland and Antarctic ice sheets. More meltwater pours through fractures to the base of the ice, where it lubricates movement, accelerating the flow of ice toward the ocean. This leads to more rapid crumbling of the toes of glaciers to form icebergs that melt in the ocean.

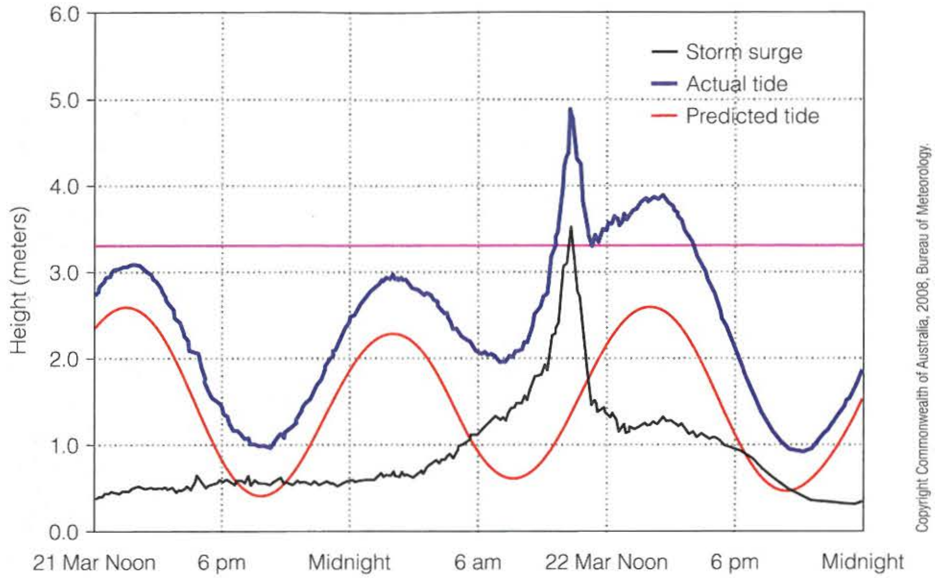
In other cases, an increase in one factor may actually lead to a decrease in a related result. Often as costs of a product or service go up, usage goes down. With increased costs of hydrocarbon fuels, people conserve more and thus burn less. A rapid increase in the price of gasoline in 2008 led people to drive less and to trade in large SUVs and trucks for smaller cars. In some places, commuter train, bus, and bicycle use increased dramatically. With the rising cost of electricity, people are switching to compact fluorescent bulbs and using less air conditioning. These changes had a noticeable effect on greenhouse gases and their effect on climate change (discussed in Chapter 10).

Sometimes major natural events are preceded by a series of smaller **precursor events**, which may warn of the impending disaster. Geologists studying the stirrings of Mount St. Helens, Washington, before its catastrophic eruption in 1980 monitored swarms of earthquakes and decided that most of these recorded the movements of rising magma as it squeezed upward, expanding the volcano. Precursor events alert scientists to the potential for larger events, but events that appear to be precursors are not always followed by a major event.

The relationships among events are not always clear. For example, an earthquake occurred at the instant Mount St. Helens exploded, and the expanding bulge over the rising magma collapsed in a huge landslide. Neither the landslide nor the earthquake caused the formation of molten magma, but did they trigger the final eruption? If so, which one triggered the other—the earthquake, the landslide, or the eruption? One or more of these possibilities could be true in different cases.

Events can also overlap to amplify an effect. Most natural disasters happen when a number of unrelated variables overlap in such a way that they reinforce each other to amplify an effect. If the high water of a hurricane storm surge happens to arrive at the coast during the daily high tide, the two reinforce each other to produce a much higher storm surge (**FIGURE 1-9**, p. 8). If this occurs on a section of coast that happens to have a large population, then the situation can become a major disaster. Such a coincidence caused the catastrophic hurricane that killed 8,000 people in Galveston, Texas, in 1900. Bad luck prevailed.

FIGURE 1-9 **AMPLIFICATION OF OVERLAPPING EFFECTS**



If events overlap, their effects can amplify one another. In this example, a storm surge (black line) can be especially high if it coincides with high tide (red line). The blue line shows the much higher tide that resulted when the tide overlapped with the storm surge.

Mitigating Hazards

Because natural disasters are not easily predicted, it falls to governments and individuals to assess their risk and prepare for and mitigate the effects of disasters. **Mitigation** refers to efforts to prepare for a disaster and reduce its damage. Mitigation can include engineering projects like levees, as well as government policy and public education. In each chapter of this book, we examine mitigation strategies related to specific disasters.

Land-Use Planning

One way to reduce losses from natural disasters is to find out where disasters are likely to occur and restrict development there, using **land-use planning**. Ideally, we should prevent development along major active faults by reserving that land for parks and natural areas. We should also limit housing and industrial development on floodplains to minimize flood damage and along the coast to reduce hurricane and coastal erosion losses. Limiting building near active volcanoes and the river valleys that drain them can curtail the hazards associated with eruptions.

It is hard, however, to impose land-use restrictions in many areas because such imposition tends to come too late. Many hazardous areas are already heavily populated, perhaps even saturated with inhabitants. Many people want to live as close as they can to a coast or a river and resent being told that they cannot; they oppose attempts at land-use restrictions because they feel it infringes on their property rights. Almost any attempt to regulate land use in the public interest is likely to ignite intense political and legal opposition.

Developers, companies, and even governments often aggravate hazards by allowing—or even encouraging—people to move into hazardous areas. Many developers and private individuals view restrictive zoning as an infringement on their rights to do as they wish with their land. Developers, real estate agents, and some companies are reluctant to admit the existence of hazards that may affect a property for fear of lessening its value and scaring off potential clients (**FIGURE 1-10**, p. 9). Most local governments consider news of hazards bad for growth and business. They shun restrictive zoning or minimize possible dangers for fear of inhibiting improvements in their tax base. As in other venues, different groups have different objectives. Some are most concerned with economics, others with safety, still others with the environment.

Insurance

Some mitigation strategies help with recovery once a disaster occurs. Insurance is one way to lessen the financial impact of disasters after the fact. People buy property **insurance** to shield themselves from major losses they cannot afford. Insurance companies use a formula for risk to establish premium rates for policies. **Risk** is essentially a

FIGURE 1-10 RISKY DEVELOPMENT

David Hyndman.

Some developers seem unconcerned with the hazards that may affect the property they sell. High spring runoff floods this proposed development site in Missoula, Montana.

hazard considered in the light of its recurrence interval and expected costs (**By the Numbers 1-2**: Assessing Risk). The greater the hazard and the shorter its recurrence interval, the greater the risk.

In most cases, a company can estimate the cost of a hazard event to a useful degree of accuracy, but its recurrence interval is hardly better than an inspired guess. The history of experience with a given natural hazard in any area of North America is typically less than 200 years. Large events recur, on average, only every few decades or few hundred years or even more rarely. Estimating risk for these events becomes a perilous exercise likely to lose a company large amounts of money. In some cases, most notably floods, the hazard and its recurrence interval are both firmly enough established to support a rational estimate of risk. But the amount of risk and the potential cost to a company can be so large that a catastrophic event would put the company out of business. Such a case explains why private insurance companies are not eager to offer disaster policies.

The uncertainties of estimating risk make it impossible for private insurance companies to offer affordable policies to protect against many kinds of natural disasters. As a result, insurance is generally available for events that present relatively little risk, mainly those with more or less dependably long recurrence intervals. The difficulty of obtaining policies from private insurers for certain types of natural hazards has inspired a variety of governmental programs. Earthquake insurance is available in areas such as Texas, where the likelihood of an earthquake is low. In California, where the risks and expected costs are much higher, insurance companies are required to provide earthquake coverage. As a result, companies now make insurance available through the California Earthquake Authority, a consortium of compaies. Similarly, most hurricane-prone southeastern states have mandated insurance pools that provide property insurance where individual private companies are unwilling to provide it.

Insurance for some natural hazards is simply not available. Landslides, most mudflows, and ground settling or swelling are too risky for companies, and each potential hazard area would have to be individually studied by a scientist or engineer who specialized in such a hazard. The large number of variables makes the risk too difficult to quantify; it is too expensive to estimate the different risks for the relatively small areas involved.

A critical question arises for people who lose their houses in landslides and are still paying on a mortgage. They may not only lose what they have already paid into the mortgage or home loan, but can be obligated to continue paying off a loan on a house that no longer exists. However, California, for example, has a law that generally prevents what are called "deficiency judgments" against such mortgage holders. This permits home owners to walk away from their destroyed homes, and the bank cannot go after them for the remainder of the loan. However, the situation is not always clear, because federal law may overrule state law. A federal agency, such as the Veterans Administration, which guarantees some mortgages, may pay a bank the balance of a loan and then go after the borrower for the remainder.

By the Numbers 1-2

Assessing Risk

Insurance costs are actuarial: they are based on past experience. For insurance, a "hazard" is a condition that increases the severity or frequency of a loss.

Risk $\propto$ [probability of occurrence] $\times$ [cost of the probable loss from the event]

The Role of Government

The United States and Canadian governments are involved in many aspects of natural hazard mitigation. They conduct and sponsor research into the nature and behavior of many kinds of natural disasters. They attempt to find ways to predict hazardous events and mitigate the damage and loss of life they cause. Governmental programs are split among several agencies.

The U.S. Geological Survey (USGS) and Geological Survey of Canada (GSC) are heavily involved in earthquake and volcano research, as well as in studying and monitoring stream behavior and flow. The National Weather Service monitors rainfall and severe weather and uses this and the USGS data to try to predict storms and floods.

The Federal Emergency Management Agency (FEMA) was created in 1979, primarily to bring order to the chaos of relief efforts that seemed invariably to emerge after natural disasters. After the hugely destructive

Midwestern floods of 1993, it has increasingly emphasized hazard reduction. Rather than pay victims to rebuild in their original unsafe locations, such as floodplains, the agency now focuses on relocating them. Passage of the Disaster Mitigation Act in 2000 signals greater emphasis on identifying and assessing risks before natural disasters strike and taking steps to minimize potential losses. The act funds programs for hazard mitigation and disaster relief through FEMA, the U.S. Forest Service, and the Bureau of Land Management.

To determine risk levels and estimate loss potential from earthquakes, federal agencies such as FEMA use a computer system called HAZUS (Hazard United States). It integrates a group of interdependent modules that include potential hazards, inventories of the hazards, direct damages, induced damages, direct economic and social losses, and indirect losses.

Unfortunately, some government policy can be counterproductive, especially when politics enter the equation. In some cases, disaster assistance continues to be provided without a large cost-sharing component from states and local organizations. Thus, local governments continue to lobby Congress for funds to pay for losses but lack incentive to do much about causes. FEMA is charged with rendering assistance following disasters; it continues to provide funds for victims of earthquakes, floods, hurricanes, and other hazards. It remains reactive to disasters, as it should be, but is only beginning to be proactive in eliminating the causes of future disasters. Congress continues to fund multimillion-dollar Army Corps of Engineers projects to build levees along rivers and replenish sand on beaches. The Small Business Administration disaster loan program continues to subsidize credit to finance rebuilding in hazardous locations. The federal tax code also subsidizes building in both safe and hazardous sites. Real estate developers benefit from tax deductions, and ownership costs, such as mortgage interest and property taxes, can be deducted from income. A part of uninsured "casualty losses" can still be deducted from a disaster victim's income taxes. Such policies do not discourage future damages from natural hazards.

The Role of Public Education

Much is now known about natural hazards and the negative impacts they have on people and their property. It would seem obvious that any logical person would avoid such potential damages or at least modify their behavior or their property to minimize such effects. However, most people are not knowledgeable about potential hazards, and human nature is not always rational. Until someone has a personal experience or knows someone who has had such an experience, most people subconsciously believe *It won't happen here* or *It won't happen to me*. Even knowledgeable scientists aware of the hazards, the odds of their occurrence, and the costs of an event do not always act appropriately. Compounding the problem is the lack of tools to reliably predict specific locations and timing of many natural hazards.

Unfortunately, a person who has not been adversely affected in a serious way is much less likely to take specific steps to reduce the consequences of a potential hazard. Migration of the population toward the Gulf and Atlantic coasts accelerated in the last half of the twentieth century and still continues. Most of those new residents, including developers and builders, are not very familiar with the power of coastal storms. Even where a hazard is apparent, people are slow to respond. Is it likely to happen? Will I have a major loss? Can I do anything to reduce the loss? How much time will it take, and how much will it cost? Who else has experienced such a hazard?

Several federal agencies have programs to foster public awareness and education. The Emergency Management Institute—in cooperation with FEMA, the National Oceanic and Atmospheric Administration (NOAA), USGS, and other agencies—provides courses and workshops to educate the public and governmental officials. Some state emergency management agencies, in partnership with FEMA and other federal entities, provide workshops, reports, and informational materials on specific natural hazards.

Given the hesitation of many local governments to publicize natural hazards in their jurisdictions, people need to educate themselves. Being aware of the types of hazards in certain regions allows people to find evidence for their past occurrence. It also prepares them to seek relevant literature and ask appropriate questions of knowledgeable authorities.

One of the best means of protecting ourselves from natural hazards is an ability to recognize landscapes and rocks and to understand the processes that shape them. Volcanoes not only shed lava flows but ash and mudflows that can be recognized in ancient deposits. Old landslides often leave lumpy landscapes, and sinkholes can leave closed, undrained depressions. Streams meander across flat floodplains, shifting their channels by eroding meander banks. Storm waves undercut sea cliffs and churn sand from beaches. Offshore barrier islands are eroded on their seaward sides, depositing sand landward; that moves the islands landward. Homes in the urban fringe are often burned by wildfires that creep along the ground in dry leaves and needles, even though surrounding trees survive. We study landscapes and the processes that shape them in the chapters that follow.

Some people are receptive to making changes in the face of potential hazards. Some are not. The distinction depends partly on knowledge, experience, and whether they feel vulnerable. A person whose house was badly damaged in the 1989 Loma Prieta, California, earthquake is likely to either move to a less earthquake-prone area or live in a house that is well braced for earthquake resistance. A similar person losing his home to a landslide is more likely to avoid living near a steep slope. The best window of opportunity for effective hazard reduction is immediately following a disaster of the same type. Studies show that this opportunity is short—generally, not more than two or three months.

Successful public education programs, such as some of those on earthquake hazards in parts of California presented by the USGS, have shown that information must come from multiple credible sources and be presented in nontechnical terms that spell out specific steps people can take. Broadcast messages can be helpful, but written material that people can refer to should accompany them. Discussion among potentially affected groups can help them understand hazards and act on the information. If people think the risk is plausible, they tend to seek additional reliable information to validate what they have heard. And the range of additional sources must be trustworthy to different groups of people. Some groups believe scientists; others favor structural engineers. Some seek out information online. Successful education programs must include specialists and should adapt material to the different interests of specific groups, such as homeowners, renters, and corporations. Overall, natural hazard education depends on tailoring a clear message to different audiences using nontechnical language. It must not only convey the nature of potential events but also show that certain relatively simple and inexpensive actions can substantially reduce potential losses.

Living with Nature

Catastrophic events are natural and expected, but the most common human reaction to a current or potential catastrophe is to try to stop ongoing damage by controlling nature. In our modern world, it is sometimes hard to believe that scientists and engineers cannot protect us from natural disasters by predicting them or building barriers to withstand them. But there are limits to scientific understanding and engineering capabilities. In fact, although scientists and engineers understand much about the natural world, they understand less than many people suppose.

Unfortunately, we cannot change natural system behaviors, because we cannot change natural laws. Most commonly, our attempts tend only to temporarily hinder a natural process while diverting its damaging energy to other locations. In other cases, our attempts cause energy to build up and produce more severe damage later.

If, through lack of forethought, you find yourself in a hazardous location, what can you do about it? You might build a river levee to protect your land. Or you might build a rock wall in the surf to stop sand from leaving your beach and undercutting the hill on which your house is built.

If you do any of these things, however, you merely transfer the problem elsewhere, to someone else, or to a later point in time. For example, if you build a levee to prevent a river from spreading over a floodplain and damaging your property, the flood level past the levee will be higher than it would have been without it. Constricting river flow with a levee also backs up floodwater, potentially causing flooding of an upstream neighbor's property. Deeper water also flows faster past your levee, so it may make for worse erosion of a downstream neighbor's riverbanks. As in the stock market, individual stocks go up and down. If you make money because you bought a stock when its price was low and sold it when its price was high, then you effectively bought it from someone else who lost money. In the stock market, over the short term, the best we can do, from a selfish point of view, is to shift disasters to our neighbors. The same is true when tampering with nature. We need to understand the consequences.

Individually and as a society, we must learn to live with nature, not try to control it. Mitigation efforts typically seek to avoid or eliminate a hazard through engineering. Such efforts require financing from governments, individuals, or groups likely to be affected. Less commonly, but more appropriately, mitigation requires changes in human behavior. Behavioral change is usually much less expensive and more permanent than the necessary engineering work. In recent years, governmental agencies have begun to learn this lesson, generally through their own mistakes. In a few places along the Missouri and Sacramento Rivers, for example, some levees are being reconstructed back from the riverbanks to permit water to spread out on floodplains during future floods.

Natural hazards exist worldwide. They depend on climate, topography, tectonic environment, and proximity to rivers and coasts. However, they are not constrained by national boundaries. The same natural hazards and processes that we see in the United States also operate, for example, in France, Argentina, New Zealand, and China. Although many of the examples you read about and photos you see in this book are from other regions, most are relevant to places much closer to home. We use good examples from other regions to amplify what can happen here. We use many of our own photos to help you recognize natural hazards and to emphasize that there is nothing unusual about what is shown in these pictures. You can easily learn to spot hazards wherever you are. The Critical View exercises at the end of many chapters provide practice for observing and analyzing hazards around you.

In reality, few places are completely free of all natural hazards. Given the constraints of health, education, and livelihood, we can minimize living in the most hazardous areas. We can avoid one type of hazard while tolerating a less ominous one. Above all, we can educate ourselves about natural hazards and their controls, how to recognize them, and how to anticipate increased chances of a disaster. Although prediction may not be realistic, we can forecast the likelihood of certain types of occurrence that may endanger our property or physical safety. This book provides the background you need to be knowledgeable about natural hazards.

Chapter Review

Key Points

Catastrophes in Nature

- Many natural processes that we see are slow and gradual, but occasional sudden or dramatic events can be hazardous to humans.
- Hazards are natural processes that pose a threat to people or their property.
- A large event becomes a disaster or catastrophe only when it affects people or their property. Large natural events have always occurred but do not become disasters until people place themselves in harm's way.
- More common and less dramatic hazards, such as heat, cold, and flooding, often have higher associated fatalities than rare but dramatic hazards, such as earthquakes and volcanoes. **FIGURE 1-4**.
- Developed countries lose large amounts of money in a major disaster; poor countries lose larger numbers of lives.

Predicting Catastrophe

- Events are often neither cyclic nor completely random.
- Although the precise date and time for a disaster cannot be predicted, understanding the natural processes that control them allows scientists to forecast the probability of a disaster striking a particular area.
- Statistical predictions or recurrence intervals are average expectations based on past experience.
- There are numerous small events, fewer larger events, and only rarely a giant event. We are familiar with the common small events but, because they come along so infrequently, we tend not to expect the giant events that can create major catastrophes. **FIGURE 1-6**, **By the Numbers 1-1**.
- Many natural features and processes are fractal—that is, they have similarities across a broad range of sizes. Large events tend to have characteristics that are similar to smaller events. **FIGURE 1-7**.

Relationships among Events

- Different types of natural hazards often interact with, or influence, one another. **FIGURE 1-8**.
- Natural processes can have a cascading, or domino effect, with one change triggering other, more rapid changes.
- Overlapping influences of multiple factors can lead to the extraordinarily large events that often become disasters. **FIGURE 1-9**.

Mitigating Hazards

- Mitigation involves efforts to avoid disasters rather than merely dealing with the resulting damages.
- Risk is proportional to the probability of occurrence and the cost from such an occurrence. **By the Numbers 1-2**.
- People need to be educated about natural processes and how to learn to live with and avoid the hazards around them.

Living with Nature

- Erecting a barrier to some hazard will typically transfer the hazard to another location or to a later point in time.
- Humans need to learn to live with some natural events rather than trying to control them.