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THE NATURAL HISTORY of Natural Hazards

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The phrase "natural hazard" is usually taken to mean a type of geophysical occurrence, such as a drought, flood, earthquake, volcanic eruption, or severe storm, that has the potential to kill and injure large numbers of people; to destroy roads, buildings, and crops; to kill large numbers of livestock; and to generally disrupt the physical, economic, and social structure of a sizeable community. When such an event strikes a vulnerable community with sufficient severity and causes such destruction, it is called a "natural disaster."

There are other kinds of "natural" hazards that can lead to disasters. Biological hazards include diseases and plagues, which can lead to epidemics and famines. There are geochemical disasters, such as the eruptions of toxic gasses from volcanic crater lakes that killed nearly 2,000 people in Cameroon in 1984 and 1986. Forest and brush fires destroy annually the vegetative cover of millions of acres of land, leaving the soil vulnerable to erosion and decay. Hazards are also caused by people and technology: transportation accidents, petrochemical explosions, mine fires, building collapses, oil spills, hazardous waste leaks, and nuclear power plant failures. Many complex hazards have both natural and human components: erosion and desertification caused by deforestation and overgrazing during a time of drought; floods caused by dam failures; and landslides caused by poorly planned construction of roads on already unstable hillsides.

Whatever their cause, disasters have biological, geophysical, political, economic, and social implications, all of which are critical in understanding and implementing emergency medical care and other measures aimed at restoring the physical and mental health of affected communities. This chapter focuses on natural hazards that have a significant geophysical component and which can result in disasters.

NATURAL AND GEOPHYSICAL HAZARDS

There are many kinds of natural hazards. Some are geophysical; that is, their causes and manifestations are rooted in the physics of the planetary mass and its envelope of air and water. Geophysical hazards include landslides, earthquakes, volcanic eruptions, tsunamis, tropical cyclones (the generic name for the storms called "hurricanes" in the United States), tornadoes, floods, droughts, and various forms of climatic change. Some geophysical hazards have biological and chemical components. Drought is a natural hazard with a geophysical cause, i.e., lack of water, but the devastating impact of drought lies in its effect on soil, vegetation, agriculture, and livestock. Thus, it has a significant biological component. Recent eruptions of toxic gasses from several lakes in Cameroon—disasters that are still not well

understood—are partly geochemical in origin. Other hazards that are primarily or completely biological in nature include plagues, epidemics, and famines.

Natural hazards not caused or influenced by people include earthquakes, volcanic eruptions, tsunamis, tropical cyclones, and tornadoes. Other natural hazards can be caused or exacerbated by human activities. Massive deforestation and the burning of fossil fuels can lead to climatic changes; poor agricultural practices can lead to desertification; poorly planned hillside development can cause landslides; and poor food production, storage, and distribution practices can combine with drought to cause famine.

Regardless of the nature or origin of a particular disaster, injuries and destruction are usually caused by forces associated with physical impact; inundation by water; collapse of structures; burial under soil and debris; fire; insufficient or contaminated supplies of food, water, or fuel; toxic substances; and disease. Highways, pipelines, and communication systems are often disrupted, hampering fire fighting, search and rescue, transportation of the injured to hospitals, and delivery of food, water, clothing, and emergency medical supplies.

Within the research and emergency management professions, a community of "natural hazard" experts and institutions has emerged whose attention is directed largely toward hazards that are entirely or primarily geophysical in nature. Biological and chemical disasters and fires are generally not addressed by this community, but rather by medical, fire safety, and public health officials. The phrase "natural hazard" almost always refers to "geophysical hazard."

Hazards, Disasters, and Vulnerability

A number of geophysical (i.e., geological, hydrological, meteorological, and oceanographic) phenomena pose threats to civilization. Fog, frost, hail, lightning, heavy rain, blizzards, ice storms, severe storms at sea, and extreme wind shear near airports are frequently responsible for injuries, deaths, and property damage. The effects of these hazards are either highly localized and intense or broadly diffused and subdued, so that death and damage are normally not on the scale associated with a disaster. Hazardous geophysical phenomena that are relatively less frequent, but which affect large areas and populations and can reach catastrophic proportions, include earthquakes, volcanic eruptions, tropical cyclones, floods, and droughts.

Not all volcanic eruptions, floods, or earthquakes are disasters. Disasters are defined on the basis of their societal consequences, not on the basis of the phenomena that cause them. Whether or not a particular event becomes a disaster depends on the magnitude, intensity, and duration of the event, and the vulnerability of the community.

For example, an earthquake is simply an event in nature. A monumental quake is not a disaster unless it creates large numbers of injuries and deaths, destroys substantial property, or causes significant community disruption. A very weak earthquake or an earthquake that occurs in an uninhabited area is mainly of scientific interest and not considered a disaster. Because earthquakes can cause destruction, they are considered geophysical hazards.

When an earthquake occurs, it may not lead to a major disaster. The 1971 San Fernando earthquake in southern California registered 6.4 on the Richter scale, but caused only minor damage and 58 deaths. An earthquake of similar magnitude (Richter 6.2) struck Managua, Nicaragua, 2 years later, and reduced the center of the city to rubble, killing approximately 6,000 people. The difference lay in the vulnerability of the two communities, defined as the susceptibility of buildings, infrastructure, economy, and natural resources to damage from natural hazards. While communities in developed nations may be just as prone to geophysical hazards as communities in poor nations, the wealthier communities are often less vulnerable to damage. Although Tokyo, Japan, and Managua, Nicaragua, are prone to earthquakes, Tokyo is less vulnerable to damage because of strictly enforced building codes, zoning regulations, earthquake preparedness training, and communications systems.

Kinds of Geophysical Hazards

Geophysical hazards either develop gradually and persist for a long time, or arise suddenly with rapid resolution. Drought, desertification, sea level rise, and climatic changes (e.g., so-called "climatic optimums" and "little ice ages" that occurred at intervals during the past few thousand years) have rendered different parts of the world better or worse suited to agriculture, and are examples of slowly developing, long-lived hazards. Earthquakes, volcanic eruptions, tsunamis, floods, tropical cyclones, tornadoes, and avalanches exemplify rapid-onset, cataclysmic hazards. Some disasters fall between these two categories. Slow moving landslides, as well as short-lived fluctuations in climate, such as "El Niño"*, are examples. The physical aspects of sudden

*"El Niño" is a warming of surface waters of the equatorial eastern Pacific that occurs at irregular intervals and lasts from several months to one or more years. It is caused by shifts in the usual wind and ocean current patterns across the tropical Pacific. The first signs of this change are often seen around Christmas time; hence the name El Niño "The Child." A typical El Niño occurrence affects local fish and bird life and causes heavy rain on the normally arid South American coast, which in turn leads to regional flooding and soil erosion. A severe El Niño occurrence (e.g., as in 1982–1983) can affect rainfall patterns, agriculture, and food supplies on a global scale.

hazards are studied by geologists (including seismologists and vulcanologists), hydrologists, meteorologists, oceanographers, and engineers, as societal aspects are addressed by architects, city planners, sociologists, political scientists, economists, and geographers. Slow-onset conditions are also the concern of botanists, zoologists, ecologists, soil scientists, and specialists in various aspects of forestry and agriculture.

Some geophysical hazards always have the same cause. For instance, tornadoes are always caused by thermal instability that occurs when cool dry air passes over hot moist land. Other hazards have a variety of causes. Floods can be caused by melting winter snows (the case with many regularly recurring riverine floods), by local heavy rainfall (most flash floods in mountain canyons), by tropical cyclones, or by tsunamis.

Some geophysical hazards have more than one destructive component. In tropical cyclones, damage is caused by heavy winds and flooding. Such flooding is further characterized by river and stream flooding from the heavy rains, and inundation of coastal areas by storm surges (unusually high sea levels).

Geophysical hazards may kill people directly, usually by drowning, burial, or with the forces associated with moving air (tornadoes), moving water (tsunamis), or solid objects such as rocks, trees, vehicles, boats, and pieces of buildings carried by moving air and water. Hazards may damage buildings, roads, dams, pipelines, and electric power lines. Death may also occur as a result of structural failure and collapse, fires, and disruption of food and water distribution and of waste disposal facilities.

One geophysical hazard may trigger another. Torrential rains cause landslides and floods. Earthquakes and volcanic eruptions cause landslides and tsunamis; the tsunamis in turn cause floods. Such hazards may be difficult to classify. For example, when a dam failure causes water to run down a valley, and the water picks up rock and soil, the event may be classified as a dam failure, flood, or debris flow.

Geophysical hazards vary considerably with regard to predictability. Slowly developing disasters such as droughts are usually not predicted, but detected at the onset. If they are carefully monitored, there is usually ample time to develop relief plans, although modern coping strategies are not very effective. Some meteorological and hydrological disasters can be predicted fairly well. Floods caused by melting of winter snow can usually be predicted weeks or even months in advance. Tropical cyclones can usually be predicted a number of days in advance, although the locations of impact cannot be pinpointed with great accuracy more than 24–36 hours ahead. Hazards such as tornadoes and flash floods caused by severe local thunderstorms can often not be predicted more than minutes in advance, although it is often possible to identify several hours in advance areas in which they might occur. Prediction of earthquakes and volcanic eruptions is a matter of chance. Often, the best that can be done is to indicate a likelihood and to carry out careful monitoring for decades to detect the first sign of the event.

Two categories of geophysical events sometimes considered natural hazards are not discussed in this chapter. The first category consists of very rare geophysical and astrophysical events such as resurgent calderas, meteor impacts, and collisions between the earth and asteroids or comets. These events may occur as often as once every few centuries or as infrequently as once every few tens of thousands of years. Although the disaster potential is great, we lack data to fully characterize these natural disasters. The second category consists of widespread, relatively minor phenomena that damage property but do not generally cause loss of life. These include slow-moving landslides, land subsidence, sinkholes, and soils that swell and shrink with changes in moisture. The economic losses associated with these hazards are usually an aggregate of many small, noncatastrophic losses; they are usually diffused over a large area, and they do not generally cause significant disruption to individual communities. However, they may contribute to disasters by weakening dams, pipelines, and roadbeds, or by lowering the land surface and increasing vulnerability to flooding.

The Consequences of Geophysical Disasters

It is conservatively estimated that between 1.5 million and 2 million people have been killed in sudden-onset geophysical disasters since 1946. This is equivalent to an average annual death toll of roughly 35,000 to 50,000. On approximately 20 occasions during that period, individual disasters have claimed more than 10,000 lives (Table 14-1). The biggest killers are earthquakes, tropical cyclones, and floods.

The number of fatalities fluctuates widely from year to year. In some years, up to half a million may die; in other years, fewer than 10,000. On two occasions, the tropical cyclone that struck Bangladesh in 1970 and the earthquake in Tangshan, China, in 1976, single disasters killed more than a quarter of a million people. Earthquakes and tropical cyclones as severe as these are infrequent, but individually kill the most people. Many other types of hazards, particularly floods, are more common and individually less destructive, but produce significant aggregate death tolls. Most natural disaster deaths are concentrated in a relatively small number of communities, predominately in the poorer nations of Asia, Latin America, and Oceania. In comparison, North America, Europe, Japan, and Australia have aver-

Table 14-1. Sudden-Onset Geophysical Disasters During the Period from 1946 to 1985 that Caused 10,000 or More Deaths

Year	Event	Location	Approximate Death Toll
1949	Floods	China	57,000
1954	Floods	China	40,000
1960	Earthquake	Morocco	12,000
1962	Earthquake	Iran	12,000
1963	Tropical Cyclone	Bangladesh	22,000
1965	Tropical Cyclone	Bangladesh	17,000
1965	Tropical Cyclone	Bangladesh	30,000
1965	Tropical Cyclone	Bangladesh	10,000
1968	Earthquake	Iran	12,000
1970	Earthquake/Avalanche	Peru	70,000
1970	Tropical Cyclone	Bangladesh	250,000–500,000
1971	Tropical Cyclone	India	10,000–25,000
1976	Earthquake	China	225,000–650,000
1976	Earthquake	Guatemala	24,000
1977	Tropical Cyclone	India	20,000
1978	Earthquake	Iran	25,000
1985	Tropical Cyclone	Bangladesh	10,000
1985	Earthquake	Mexico	10,000
1985	Volcanic Eruption	Colombia	22,000

age annual death tolls that rarely exceed a few hundred persons.

Natural disasters disrupt economies and create financial chaos. Damaged factories, crops, and livestock lead to lost investments and jobs, and failed businesses. During an emergency, people must devote time to disaster-related activities such as search and rescue or caring for survivors, so that normal economic activities are severely curtailed even if sources of employment are unaffected. Subsistence farmers, fishermen, and others who participate only marginally in the economy are affected most severely. The cost of relief and reconstruction creates a financial burden for most governments. Increased expenditures for health care, aid to the unemployed, and repair and replacement of homes and businesses are required at a time when there are decreased public resources due to the overall decrease in economic activity.

Poorly conceived relief efforts can recreate vulnerable conditions. Many relief agencies rush to reconstruct housing after a tropical cyclone despite an absence of expertise in housing, construction, and city planning. Scores of reconstruction programs systematically rebuild thousands of structures that can be as dangerous as the houses they replace. Finally, relief and reconstruction efforts compete with development programs for available funds. In countries where natural disasters occur frequently, this can create an enormous financial burden. Fiji is a good example. During the 1970s, the country was struck repeatedly by tropical cyclones, which forced the government to commit a large portion of foreign aid to reconstruction. In the early 1980s, roughly 20% of foreign aid was spent on overhead costs for reconstruction efforts from four separate cyclones.

There is no comprehensive compilation of data on economic losses from sudden-onset geophysical hazards, but a few examples illustrate the scale of the problem. Annual worldwide losses due to tropical cyclones are estimated at between $6 and $7 billion. For landslides, the comparable figure exceeds $1 billion. Seven major disasters that struck Latin American nations between 1972 and 1985 caused at least $16 billion in losses; losses attributable to individual disasters varied from $200 million to $4.5 billion. These figures merely

hint at the human impact of destruction. The eruption of Colombia's Nevado del Ruiz volcano in 1985 killed approximately 22,000 people, and left 10,000 more homeless. More than 600,000 people were left homeless in Dominica and the Dominican Republic after Hurricane David in 1979, and more than 300,000 were left homeless in Nicaragua after the Managua earthquake of 1972.

Although sudden-onset geophysical disasters can cause major economic losses in developed nations (individual tropical cyclones striking the U.S. mainland have inflicted as much as $2 billion in losses, and floods caused by heavy rain in Nagasaki, Japan, in 1982 caused approximately $1 billion in losses), the relative human, economic, and social impacts of natural disasters are usually greatest in small, poor nations. Hurricane Allen struck St. Lucia in 1980 and destroyed 90% of the island's banana crop, which normally accounts for 80% of the country's agricultural output. The previous year, Hurricane David inflicted similar losses on Dominica by destroying 85% of its banana crop. The 1985 earthquake in Mexico City caused economic losses equivalent to roughly 3.5% of Mexico's gross national product (GNP). Hurricane Fifi in 1974 caused losses in Honduras that exceeded 35% of the country's GNP; Hurricane Allen in 1980 caused losses in St. Lucia equivalent to 89% of the nation's GNP. In a recent survey of 38 natural disasters that occurred between 1977 and 1981, nine were found to have caused losses in individual countries greater than 5% of the nation's GNP. Seven of these occurred in relatively undeveloped island nations.

Economic losses from sudden-onset geophysical hazards are increasing at a rapid pace. In the U.S., damage to buildings from earthquakes, tropical cyclones, and floods is expected to increase from approximately $6 billion in 1978 to more than $11 billion in the year 2000 if no additional loss reduction measures are undertaken. A major earthquake in Tokyo would likely kill more than 30,000 people, cause the collapse of more than 60,000 houses, and set fire to more than 400,000 homes.

Slow-onset disasters take an even greater toll, but precise figures are hard to come by. Drought currently affects more people than any other natural disaster; worldwide, droughts have been estimated to affect more than 18 million people each year during the 1960s and more than 24 million people each year during the 1970s. There have been estimates that during the first part of the 1980s, droughts affected up to 30 million people each year in Africa alone. (In comparison, floods were estimated to have affected 5 million people each year during the 1960s and 15 million each year during the 1970s.) Global warming is predicted in the next century from increased atmospheric carbon dioxide caused by continued deforestation and burning of fossil fuels. If this occurs, coastal cities worldwide will be inundated and agriculture will be adversely affected; the number of people affected will number in the hundreds of millions. Similar numbers will be affected if increased ultraviolet radiation is delivered to the earth's surface as a result of stratospheric ozone depletion caused by continued release of chlorofluorocarbons.

Coping with Geophysical Disasters

The difficulties faced in coping with a disaster are usually a function of the geographical extent and nature of community disruptions. When roads, communication lines, food storage facilities, water supplies, and waste disposal facilities are disrupted, the coping effort must be considerably greater than if those lifelines remain intact.

There are two major ways in which societies cope with geophysical hazards. The most obvious is by responding when a disaster strikes or when warnings indicate that a disaster is imminent. Among the steps that can be taken in response to an actual or imminent disaster are dissemination of warnings; evacuation; fire fighting; search and rescue; emergency medical care; emergency communications and transportation; provision of food, water, clothing, and temporary shelter; and measures to preserve public health and safety. These emergency response actions are most effective if there has been an organized program of disaster preparedness, including development of plans for disaster response and evacuation, stockpiling of emergency equipment, and training of emergency personnel. Once the emergency is over, rebuilding is accomplished through a program of recovery that includes post-disaster relief, technical assistance, and loans for repair and reconstruction. The second way societies cope with geophysical disasters is by planning and building communities to minimize vulnerability. Wise land use management keeps vulnerable structures and activities away from hazard-prone locations, utilizes building designs, materials, and construction methods that reduce the likelihood for damage during a disaster, and promotes construction of protective engineering works such as dams, dikes, levees, sea walls, diversion channels, and catchment basins. These activities collectively are termed hazard mitigation.

SLOW-ONSET, LONG-LIVED HAZARDS

Hazards that develop slowly and persist for a long time disrupt the equilibrium between human society and nature. Certain types of economically valuable activities such as farming, fishing, mining, electric power generation, and manufacturing are most successful in locations with appropriate topography, soil, water resources, and so forth. Human settlements develop at

locations that serve as centers for these activities. When there is no rain, the groundwater level drops, the soil becomes infertile, and the prevailing temperature changes, people and their institutions are slow to adjust. Food supplies shrink, economies fail, populations migrate, and the affected region undergoes total disruption.

Climatic changes may be global, regional, or local. Examples of global changes are the atmospheric warming and the increase in damaging ultraviolet radiation. Both have the potential for disaster. On the regional and local scales, drought is the most serious recurring slow-onset geophysical hazard. When droughts occur in regions where poor agricultural, logging, and land use practices prevail, desertification, or the extension of desert conditions to locations where they did not previously exist, can occur. Deforestation is highly significant. In addition to its contribution to global warming, deforestation leads to increased vulnerability to droughts, landslides, and floods.

CLIMATIC CHANGES

The world climate has fluctuated frequently and extensively over the past three million years. The best known major fluctuations are the successions of advancing and retreating polar ice, which once covered much of the northern portions of Europe and North America. During the past 5,000 years there have been climatic fluctuations characterized by periods of warming (climatic optimums), followed by periods of cooling ("little ice ages") that have affected temperature regimes on land and sea. The last climatic optimum occurred from the eleventh through the thirteenth century. The last "little ice age" lasted from the sixteenth through the nineteenth century. During much of that period, Europe frequently experienced cold, wet summers and poor harvests, with widespread starvation that fostered political unrest. Since 1900, there has been evidence of a global warming trend. Industry and city dwelling have created local climatic changes characterized by urban "heat islands" and increasing amounts of air pollution and smog.

Since the beginning of the Industrial Revolution, people have burned enormous quantities of fossil fuels, removing carbon from the earth and adding carbon dioxide to the atmosphere. The atmospheric concentration of carbon dioxide has already increased by 20% over its preindustrial concentration, and it is estimated that this may nearly double within the next century. The problem is further aggravated by extensive deforestation, since trees remove carbon dioxide from the atmosphere.

Atmospheric carbon dioxide is virtually transparent to incoming solar radiation, but absorbs outgoing terrestrial infrared radiation that would otherwise escape. As the carbon dioxide content of the atmosphere increases, the temperature of the atmosphere near the earth's surface is expected to rise. This will likely have two effects. The first is a change in temperature patterns (and a secondary effect in terms of changed precipitation patterns) that may affect the suitability of various parts of the world for particular crops. The second is melting of polar ice caps and glaciers to the extent that sea level may rise anywhere from 1–20 feet over the next few centuries, flooding many of the world's coastal regions.

Chlorofluorocarbons have been in widespread use for only a few decades, primarily as aerosol spray propellants, refrigerants, foaming agents, and industrial solvents. They are normally inert and do not degrade or react chemically with other substances. Consequently, all manufactured chlorofluorocarbons eventually escape to the atmosphere, where they persist for many decades, ultimately migrating to the stratosphere. They then decompose under the action of ultraviolet radiation and in the process destroy stratospheric ozone, which shields the earth from damaging ultraviolet radiation. Thus, there are likely to be future increases in the amount of damaging ultraviolet radiation reaching the earth's surface.

Changes in climate patterns on local and regional scales cause changes in rainfall. When water delivery is altered for a few months, the most serious result is likely to be regional crop failure; when it persists for several years or more, it can lead to extensive gullying and erosion, landsliding, flooding, and drought. When water use, logging, agriculture, and livestock farming are not adjusted to match the changed climate conditions, long-lived environmental problems, such as desertification, can occur.

DROUGHT

Drought is a major cause of human suffering, with the unfortunate distinction of being the natural disaster that claims the most victims. Its ability to cause widespread misery is increasing. Although drought is generally associated with semiarid climates, droughts can occur in areas that normally enjoy adequate rainfall. In the broadest sense, any prolonged occurrence of insufficient water for the normal needs of agriculture, livestock, industry, and people may be termed a drought. The cause may be lack of supply, contamination of supply, inadequate storage or conveyance facilities, or abnormally high demand. Drought is commonly understood to be a condition of climatic dryness severe enough to reduce soil moisture, surface water, and groundwater below the minimum levels necessary to sustain plant, animal, and human life.

Droughts occur on all continents. In recent decades, the most severe and devastating droughts have been in Africa, but major droughts have also occurred recently in Brazil, Chile, Bolivia, India, Australia, China, and the Philippines. The most severe occurrences in Africa were initially along the southern edge of the Sahara (the Sahelian and Sahel-Sudanian belts), but more recently in many parts of eastern and southern Africa. In addition, near-drought conditions have occurred in the grain-producing regions of the U.S. and Soviet Union. Present trends suggest that droughts are becoming more frequent on the margins of deserts and in places where agricultural, lumbering, and livestock grazing practices are changing.

Recent Droughts: Chad and Bolivia

Chad, the largest landlocked country in the Sahel region of Africa, experienced a prolonged drought during the 1970s. The drought in Chad resulted from abnormally low rainfall that lasted for several years. This resulted in a lowering of the groundwater table. In addition to this, a growing population, overgrazing, and continuous cropping put excessive pressure on an already barren land. Cereal grain production was reduced by 60% and the livestock herd was reduced by 50%. Because of inadequate data, the actual number of starvation victims and displaced persons is not known; however, it has been estimated that more than 900,000 people were severely affected.

A major effect of the drought was on livestock production. The nation's herd of 4.7 million cattle, goats, and sheep was reduced by one half, and surviving animals suffered from malnutrition and disease. Because of the importance of livestock in earning foreign exchange, the nation's economy suffered seriously.

About half of Chad's population of 4 million people lived in the drought-affected zone. As the drought persisted, many people migrated in search of relief. Some moved with their herds into neighboring countries, while others settled in urban centers within Chad. Squatter settlements grew, urban overcrowding and unemployment increased, additional burdens were placed on the country's already limited social services, and political instability increased.

The drought that occurred in Bolivia in 1983 affected a third of the country's land area and ruined 80% of the normal fall harvest of staple crops, depriving nearly 1.6 million farmers of income and food. The city of Potosi, population 104,000, was totally deprived of its normal sources of water. Livestock losses included more than 200,000 cattle, 3 million sheep, and 600,000 llamas and alpacas. The drought occurred when the eastern lowlands, traditionally an alternative source of food, had been flooded and the transportation system seriously damaged. Migration to urban areas accelerated, unemployment increased, municipal services were overburdened, and several key industries that depended on agricultural production were shut down.

Characteristics of Droughts

Droughts usually result from a combination of climatic and human causes: changing weather and climate patterns that substantially diminish rainfall; poor agricultural practices including overgrazing, inappropriate cultivation, and poor soil conservation; and increased industrial use of surface and groundwater. The available water supply is decreased and the soil's ability to retain moisture is diminished (Figure 14.1).

The most immediate and direct effects of drought are loss of crops, livestock, and water for personal and industrial use. If the drought persists, secondary effects become important, and include famine, population migrations, changes in the economic, social, and urban character of the country, increased erosion, flash flooding, ecological changes associated with the growth of scrub vegetation, and possibly desertification.

The most serious of all effects is famine, or malnutrition and starvation as a result of food shortages. Most famines are predictable, and could be avoided by appropriate programs of food storage and distribution while the drought persists. However, this places great strain on food storage and transportation resources, and many less developed countries in semi-arid regions cannot restructure food supply systems to respond to the need.

Drought Prediction

In many areas, droughts tend to recur at approximately regular intervals. Together with increased understanding of climatic change and of the impacts of industrial growth and changing agricultural practices, this may make it possible to predict a drought 1–2 years in advance. Still, failure to respond to such a prediction by storing food and changing water consumption practices negates the advantage.

DEFORESTATION

Deforestation, or removal of or damage to forest vegetation to the extent that the forest no longer supports its natural flora and fauna, usually results from unrestrained tree cutting to meet immediate needs, without concern for long-term implications. In the intermediate term, deforestation can damage watersheds and lead to increased occurrence of floods. Deforestation in semi-arid regions can, in combination with drought, lead to desertification. In the long term, massive deforestation will affect the atmospheric carbon dioxide balance, leading to global warming, receding polar ice caps, and

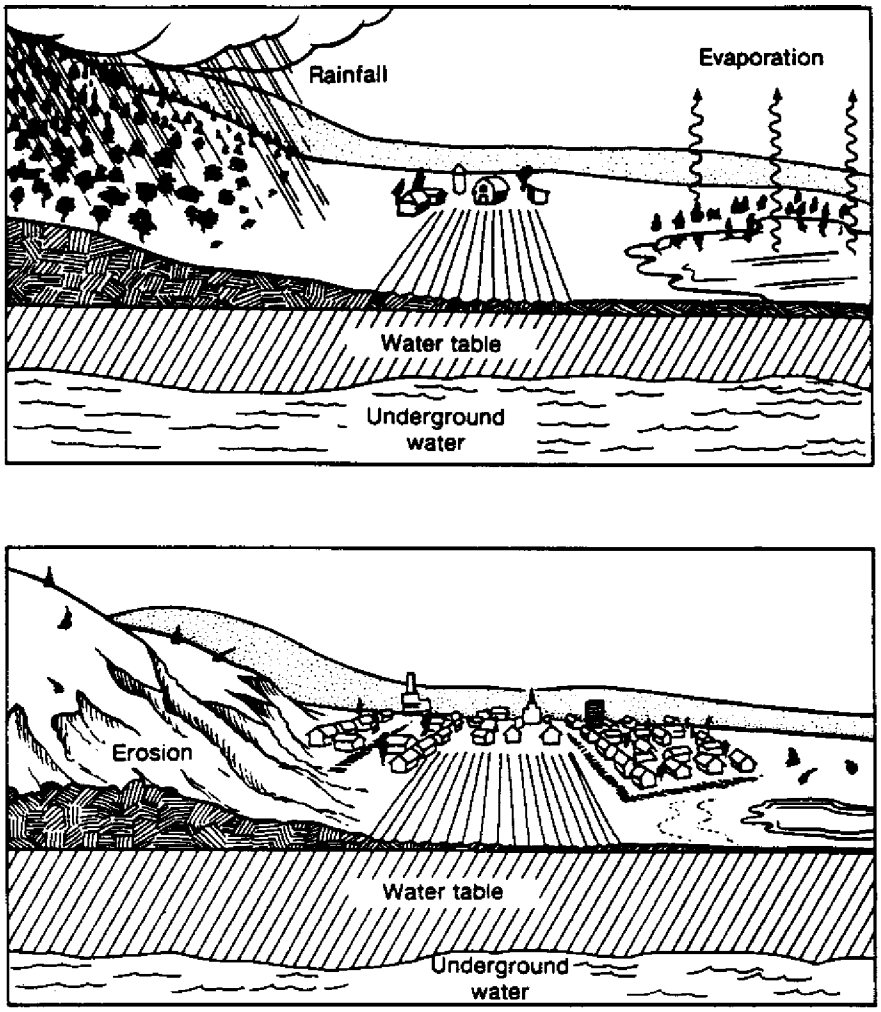

Figure 14-1. The drought cycle: Meteorological changes reduce rainfall, while urbanization, overgrazing, reforestation, and farming reduce soil water retention. As normal hydrological balance is disrupted, topsoil erodes and the water table is lowered, making recovery difficult. Food and drinking water reductions include human migration from the area. (From U. WI. Disaster Management Textbook *Natural Hazards: Causes and Effects* [U. WI. DMC])

a rise in sea level with destruction of many coastal communities and ecosystems.

The Extent and Impact of Deforestation

Approximately 20% of the earth's land surface is covered by closed forests (forests in which tree crowns cover 20% or more of the ground when viewed from above) and another 12% is covered by open woodlands (where scattered trees provide a crown cover of 5–19%). North America, the Soviet Union, northern Europe, and the humid tropical belt across central Africa, central South America, and Southeast Asia are rich in forests. Most of Africa and Asia and parts of Central and South America are forest-poor.

In many industrialized countries, accommodation has been reached between timber cutting and tree planting. In developing nations, forests are being rapidly cut down for three purposes: to create land for agriculture; to produce timber, largely for export; and to produce firewood for use as fuel (nearly half of the world's population uses wood as the primary fuel). Except where the cleared land is to be used for agriculture, no attempt is generally made to protect the soil or to replant the removed tree cover.

Throughout much of Africa, Asia, and Latin America, the forest area is shrinking. Regions of the world that were settled long ago, such as the Middle East, parts of North Africa, the Andean region of South America, and most of China and South Asia, lost the bulk of their forests in ages past, although the depletion of tree cover generally continues. Current severe human impacts upon the tree cover are unfolding in drier, lightly wooded areas of the Third World where devegetation helps create desert-like conditions and acute fuel-wood

shortages. The conversion of closed forests to scrubland or other uses occurs mainly in the humid tropics.

Since 1950, approximately half the world's remaining tree cover has been cut, primarily in the tropics. West Africa has lost more than 70% of its forests and South Asia more than 60%. In Thailand and Costa Rica, less than 40% of the forest remains; in the Philippines, less than 20%; in Java and Haiti, about 10%; and in Gambia, less than 5%. Within the next two decades, total deforestation is predicted in Burundi, the Ivory Coast, and Ethiopia. The problem is almost as severe in Kenya, Burkina Faso (formerly known as Upper Volta), Panama, Indonesia, India, Burma, and Nepal.

The Amazon Basin offers a special example of the severity of the problem and its global ramifications. This region contains one third of the world's forest land and one fifth of its fresh water, and produces half of the world's plant-generated oxygen. Tropical soils are extremely fragile, and nutrients in the system are contained almost entirely in the plants, with little reserve held in the soil. When the trees are removed the soil is exposed to desiccation by the hot sun. Fine-grained surface material shrivels, bakes, and is carried away by rain. In the past, shifting cultivators who practiced slash-and-burn farming would allow these areas to readjust over periods of a decade or so before returning to recultivate. Today, under the pressure of population growth, the land is no longer allowed to lie fallow for long. Cultivation is attempted too soon; the remaining fertility has vanished and the land become worthless for agriculture. The soil may lose its fertility for decades. Erosion further depletes the soil and produces excessive siltation in streams. Trees utilize carbon dioxide to produce oxygen and water vapor; nearly half the rain in the Amazon Basin is generated by evaporation from the forest. After deforestation, water, oxygen, and carbon dioxide balances of the atmosphere will be modified.

Deforestation and the resulting scarcity of timber have an especially harmful impact on housing in poor countries. In the late 1970s, the Indian state of Gujarat conceived an ambitious plan to construct huts for landless laborers. The plan was derailed by the lack of raw materials. The program called for 25 million wood poles, but only 400,000 of these became available each year; 765 million bamboo stalks were needed, and only four million of these were produced each year.

Deforestation's impact on food supply follows this sequence: deforestation and erosion; collapse of hillslopes; loss of topsoil and agricultural land; and decreases in crop production. Deforestation also increases the likelihood of droughts and floods.

Deforestation in Africa and Asia

In Africa, 2.3 million hectares of open woodlands are cleared each year as the vegetation of other vast areas of woodlands declines. The dense forests of West Africa, Madagascar, Rwanda, and Burundi are disappearing rapidly, although there are rain forests in parts of Central Africa that have hardly been touched. The Ivory Coast has lost 70% of the forest with which it began the twentieth century; there and in Nigeria, 10% of the accessible forest was cleared each year during the late 1970s.

Timber exporting nations of Southeast Asia share similar experiences. In peninsular Malaysia, the rate of timber production from the country's once lush forests will not be adequate to meet domestic demand within another few years. Stringent new logging controls are being imposed in Thailand following estimates that the country's forests will disappear in two decades under present logging and farming practices. Recent satellite pictures of the Philippines, traditionally a major timber exporter, indicate that forests now cover only 30% of the country; the Philippine government has estimated that a forest cover of 46% is needed for economic and environmental reasons. If present logging practices continue, all of the country's old-growth forests will disappear by the end of this century, and projected timber supplies from second-growth forests and plantations will not suffice to meet domestic needs. Destructive increases in flooding and sedimentation as a result of deforestation have already been noted.

The contribution of deforestation to flooding is impossible to estimate precisely, but as flooding worsens worldwide, increasing attention is being given to protection of watersheds. In autumn of 1978, India suffered catastrophic flooding. Following 2 days of concentrated rainfall, 66,000 villages were inundated, more than 2,000 people drowned, and 40,000 cattle were swept away. Two states, West Bengal and Uttar Pradesh, lost a total of $750 million in crops. The area annually afflicted by floods is 60% greater than it was 3 decades ago. The Indian government is beginning to investigate whether flood problems can be alleviated without restoration of forest cover in increasingly denuded hills of northern India and Nepal.

Nepal opened its borders to the outside world in 1950 and began its transformation from a closed feudal kingdom to a small mountain state, increasingly dependent on the world market. The burgeoning rural population felled trees for cooking fuel and to make room for new agricultural terraces on steeper slopes. As the nearest trees were cut first, villagers had to spend increasing amounts of time carrying fuel wood greater distances.

When a family devotes more than two person-days per week to cut and fetch fuel wood, a turning point is reached at which animal manure, the principal and often only form of fertilizer, is increasingly used for fuel. This is the current condition of almost half the rural population of Nepal. As agricultural terraced lands are deprived of manure, crop yields are lowered, necessi-

tating additional terracing of more important marginal terrain on steeper slopes, and reduced soil fertility leads to weakened soil structure and increased incidence of landsliding during the monsoon season. Torrential rains during the monsoon induce mud and debris flows, which in turn lead to flooding and siltation in lowlands.

Nepal has lost half its forest cover over the past 30 years. This situation characterizes much of the Himalayas. As a direct consequence, the Ganges delta is rapidly advancing into the Bay of Bengal, and silt in suspension can be detected 500 kilometers south of the present coastline.

Similar problems can be found farther east, typified by the Darjeeling floods of 1968. Toward the end of the monsoon season, heavy rains deluged Sikkim and West Bengal; over a three-day period, precipitation varying between 500 and 1,000 mm fell on the Himalayan foothills in the vicinity of Darjeeling. While this in itself was a rare and extreme occurrence, extensive deforestation and road construction made it a major disaster. Some 20,000 landslides occurred on the third day of rain. Approximately 30,000 people were killed, and the 60-kilometer mountain highway to Darjeeling was severed in 92 places. Many of the losses were incurred by villages and farms on the plain where the mountain streams debouch from the Siwaliks.

In regions outside the humid tropical zones, the last extensive forests in many Third World countries are on steep slopes and more remote reaches of mountains. Agriculture has traditionally been concentrated on the plains and valley floors, for severe erosion and other ecological calamities often occur when slopes are left unprotected by vegetation. Cultivators are moving up mountainsides in many parts of Africa, Asia, and Latin America, clearing forests as they go. Mountainside farming and associated deforestation is precarious, as it affects civilization downstream by increased flooding and siltation of rivers, reservoirs, and harbors.

The Process and Impact of Deforestation

Uncontrolled deforestation is usually a symptom of society's inability to control fundamental development problems, including agricultural stagnation, inequitable land tenure, unemployment, population growth, and its incapacity to regulate private enterprise to protect the public interest.

Agriculture. The spread of farming is a major cause of deforestation. Potentially arable land can still be found under forest cover in parts of Africa, Latin America, and Southeast Asia, although its extent may be exaggerated. Given the population increases in these regions, conversion of much of this land to agriculture over the coming decades will be necessary. Unfortunately, the spread of agriculture is often characterized by chaos and ecological destruction. In tropical rain forests, where little is known about soil conditions, legal and illegal colonists attempt to carve farms out of the jungle. Often, the chosen forest land cannot support permanent agriculture. When soil fertility is lost, cultivation is abandoned and the land is often grazed. This land will often return to forest, unless it is first destroyed by erosion.

Much blame for tropical forest destruction is attributed to shifting cultivators, who slash and burn a clearing, grow crops for a few years until soil fertility dissipates, and then move to a new patch. While itinerant farmers are major agents of deforestation, it is important to distinguish between different approaches to shifting cultivation. Traditional systems use planting methods adapted to the natural ecosystem (e.g., a helter-skelter, tightly woven mix of diverse plants, rather than straight rows of a single crop) and allow lengthy fallow periods during which soil fertility is restored and trees regrow on the cultivated plots. Many traditional communities in the Amazon Basin, Central Africa, and Southeast Asia still practice shifting cultivation in harmony with nature. However, when farmers are hemmed in by logging companies, encroaching plantations, or other incursions of modern society, they become enemies of the forest. Fallow cycles are shortened to the point where trees have no chance to regrow.

Many current shifting cultivators are not traditional practitioners of the art. They are people struggling to eke out subsistence in unfamiliar ecological conditions. In Indonesia, many persons who migrated from Java to the outer islands find continuous cultivation of the land to be unworkable, either because the soil is unsuitable or because there is no technical assistance. In Venezuela, a high rate of unemployment and rising numbers of landless peasants have caused 30,000 families (most of them practicing shifting cultivation) to live within national parks, forest reserves, and other supposedly protected areas. An influx of shifting cultivators in the watershed above the Panama Canal is causing increased siltation of a crucial reservoir, jeopardizing the canal's future utility and Panama City's water supply. In Central and South America, large areas of tropical forest have been cleared to create grazing lands, a transition that is sometimes unsustainable.

Firewood Collection. Firewood collection contributes significantly to depletion of tree cover, especially in areas that were originally lightly wooded. Outright destruction of live trees to meet fuel needs occurs most commonly around cities and towns with commercial markets for firewood and charcoal. Well organized syndicates bring fuel by truck, camel, and donkey cart into cities like Ouagadougou in Burkina Faso and Niamey in Niger, damaging the landscape in a widening circle.

Firewood scarcity is often most serious in areas far removed from forests designated as firewood sources.

The increase in tree planting required to meet projected fuel needs is awesome. According to World Bank calculations, the rate of firewood planting (which is now about 500,000 hectares per year in the Third World, excluding China) must increase fivefold if enormous ecological and economic costs are to be avoided.

Logging. Logging in humid tropical forests, much under the auspices of multinational corporations, usually involves "creaming" a small proportion of commercially valuable species. However, the process of cutting and removing selected trees amid dense foliage and on delicate soils usually causes far more destruction of vegetation and wildlife than suggested by the bare statistics of extracted timber. It is estimated that logging operations may damage or destroy up to 40% of the trees left behind.

DESERTIFICATION

Desertification is the deterioration of arid and semiarid lands used beyond their capacity for sustained production. Drought often accelerates deterioration, but natural ecosystems usually recover from even prolonged drought.

Roughly 15% of the world's population lives upon drylands. While deserts are not completely barren, they have very little agricultural potential. Desertification is extension or intensification of desert conditions. Desertification in developing countries worsens poverty, fosters malnutrition and disease, erodes the agricultural basis of the national economy, and leads to deterioration of living standards. During the late 1960s and early 1970s, when desertification began in the Sahel region of northern Africa (which includes Mauritania, Mali, Burkina Faso, Senegal, Niger, Chad, Sudan, and part of Ethiopia) the death rate doubled, birth rate halved, average life expectancy decreased by 10 years, soils were devastated, and 100,000 people and 10 million cattle starved or died of thirst.

Drylands, Deserts, and Desertification

Thirty percent of the world's land surface consists of potentially productive, but susceptible, drylands. This includes large stretches of the Middle East and the Sahel belt in Africa just south of the Sahara, the Kalahari in Africa, much of central Australia, much of inner Asia, Patagonia in South America, and the southwest portion of the U.S. The world's desert and semi-desert areas encompass a wide range of temperatures, ranging from the hot deserts of the Sahara and Saudi Arabia to the cold Gobi desert of central Asia. Lack of precipitation is the common feature.

Lack of precipitation may stem from a number of causes. These include a location deep in the interior of a continent far from moisture-laden oceanic winds (deserts of central Asia); a region in the rain shadow of a major mountain range, where much of the moisture carried by air currents rains on the windward side, leaving little rainfall on the leeward side (the Kalahari and parts of Patagonia); a region in a hot coastal area bordered by a cool ocean, where the moisture in maritime breezes does not condense beyond mist (the Atacama of Chile, which contains the driest place in the world, where no rain has fallen for more than 400 years); or a region situated under large, permanent high-pressure systems in which the water vapor slowly subsides and spreads out at the surface without condensation or penetration of storm systems (the vast tropical deserts of the Sahara and Saudi Arabia).

Vulnerability of a dryland region to desertification and the severity of its impact are governed by climate, topography, soil structure and texture, and vegetation type. Most significant is land use, reflected in population density of people and livestock, and the nature and extent of deforestation, agriculture, mining, road construction, and urbanization.

In drylands, vegetation constitutes an important resource that transforms solar energy into food as it protects and stabilizes the soil. Part of the plant population consists of short-lived ephemerals, plants that germinate and complete their life cycles rapidly after rain, remaining as seed through intervening dry periods. Such plants are commonly fleshy and palatable, and are preferred by grazing animals. Perennial grasses wither during dry spells and die back to the root stock or to bulbs; with fresh rain they sprout anew. These plants form more durable pastures, as extensive root systems remain in the ground to bind soil and contribute to its organic content. Longer-lived perennial plants resist water loss by adaptations, such as woody stems and leathery leaves. These include shrubs and trees, which remain nutritious during dry periods and provide an important food source to grazing animals. These plants protect the ground surface, providing shade and preserving an environment favorable to important shorter-lived plants.

Water balance in dryland ecosystems is easily disturbed. When meager vegetation is reduced by clearing or grazing, the ground surface is exposed, the organic portion of soil is mineralized by sun exposure, and the soil structure is degraded by rainfall. The sun bakes the top soil layer into a thin crust that prevents infiltration of water. Rainwater unabsorbed by soil creates rapid runoff. Where the surface has been disturbed by trampling animals, the nutrient-rich topmost soil layer may be washed away or blown off in dust storms. The remaining soil is essentially infertile and presents a hostile environment for plant growth, with the results that vegetation responds less well to rain and produces less total biomass, and many plants expire at an earlier stage

of drought. This sequence of events sets the stage for desertification.

The Course of Desertification

The natural history of desertification depends on whether land is used for grazing, irrigated farming, or rain-supported farming. In pastoral rangelands, there is initial deterioration in the composition of pastures subjected to excessive grazing in dry periods. This is typically characterized by proportionate reduction in edible perennial plants and corresponding increase in inedible and annual species. Thinning and death of vegetation during the dry season increases the extent of bare ground, followed by deterioration of surface conditions vital to plant growth. Impoverishment of plant-water relations is especially pronounced, and ephemerals respond poorly to rain. As runoff increases, sheet and gully erosion affect sloping ground, and the topsoil and its nutrient stores are lost. This results in an environment inhospitable to plant growth and less suitable as pasture. As erosion continues, formerly productive lands become useless as a result of soil stripping and gully extension. This process can be even more destructive when it occurs in upland watersheds and farmed areas where mechanical cultivation further exposes and disturbs soil.

The principal manifestations of desertification on irrigated lands are soil salinization or alkalization caused by inadequate leaching of salts contained in the soil or added in irrigation water. Salinization and waterlogging commonly occur together. Where the soil is waterlogged, upward movement of saline groundwater leaves salts on the surface when the water evaporates. On soils that are not waterlogged, salinization can occur when water containing soluble salts moves from irrigation furrows into ridges where crops are planted or onto high spots on poorly leveled land. Under-irrigation of weakly permeable soils can also lead to salinization if the irrigation water is salty.

In areas where farming is supported by rain, desertification often originates on fallow land or on land cleared for cultivation. Removal of original ground cover exposes the soil to accelerated wind and water erosion. The beating action of rain on naked soil puddles the surface, which crusts under the sun, reducing infiltration of water into the soil and further increasing runoff. This in turn leads to increased erosion which, unless halted by protective measures, ultimately strips away the fertile soil surface and exposes infertile subsoils. Gullies form on the lower portions of slopes, impeding or preventing farming operations. Sediment deposited at the foot of slopes covers plants, clogs waterways, and aggravates flooding in low-lying areas that results from increased slope runoff.

Desertification and Land Use

Desertification can be brought about through any use of drylands that does not take into account their limitations and the patchwork contrasts in productivity and vulnerability that characterize them. The problem is compounded by fluctuating climatic conditions and by overuse of drylands for sustained production. The achievement of short-lived increases in productivity through the use of inappropriate agricultural technologies, such as extensive groundwater withdrawal, deep plowing, or excessive soil pulverization through mechanical tillage, cannot be sustained in the long run.

New technologies are often introduced that were developed in more humid environments and that are not appropriate for the fragile equilibrium of dryland ecosystems. For example, introduction of deep wells can increase local availability of water, allowing larger and less mobile herds, but overgrazing and excessive trampling can start the process of soil destruction that ultimately leads to desertification. Dryland regions experience road and highway construction, mineral exploration and mining, construction of pipelines and canals, industrialization, urbanization, and recreational development. In dryland pastoral economies, large numbers of livestock tend to build up during runs of good years; these numbers cannot be supported through the inevitable ensuing drought.

Dryland farmers have a tendency after a period of good years to extend their cropgrowing onto more marginal lands. In moving into areas of greater climatological risk, they push back the pastoralists. This is particularly likely when pressure to increase land productivity is increased by population growth, by land tenure practices, or by mechanization. The unpredictable drought will find the marginal land stripped of its natural vegetative cover and vulnerable to erosion. Such land enters a period of dry years defenseless, and may emerge in too degraded a condition even to support livestock grazing.

SUDDEN-ONSET, SHORT-LIVED HAZARDS

Hazards that initiate and terminate quickly, such as earthquakes, floods, and storms, usually affect only a small region. When that region includes an urban center, large numbers of people may be affected. Where ample funds and other resources for recovery and reconstruction are available, these hazards do not usually lead to long-term or permanent disruption in the balance between people and nature. However, in many poor, developing nations, the impact is felt for many years.

Hazards of this type have both natural and human

aspects. Landslides, generally caused by geological instability, can be triggered or exacerbated by poorly planned development and construction on hillsides. Floods result from heavy rain, tsunamis, or storm surges, but can be affected by agricultural and logging practices, and urban developments that change the character of watersheds and modify potential for runoff and drainage.

Sudden-onset, short-lived hazards are of three primary types. Geological hazards include landslides, avalanches, earthquakes, and volcanic eruptions which typically involve movements of the land surface and of material on or beneath the surface. Hydrological hazards include coastal floods resulting from inundations of sea water associated with tsunamis, tropical cyclones, and other severe storms at sea; river and stream floods caused by heavy rain or by melting winter snows; and "flash" floods caused by heavy rain that accumulates in a single canyon or valley. Meteorological hazards involve wind, hail, lightning, rain, and snow associated with severe storms such as tropical cyclones, mid-latitude storms, thunderstorms, and tornadoes.

LANDSLIDES AND SNOW AVALANCHES

Landslides and snow avalanches are masses of material that move downhill. In landslides, the moving material is primarily rock and soil; in snow avalanches it is primarily ice and snow. The particular physical properties associated with snow and ice give snow avalanches a distinctive set of traits (see Chapter 15).

Landslides

Landslides are masses of material that move slowly or rapidly downslope along a hillside. The moving material may consist of soil, rock, mud, ice, or snow, be relatively homogeneous or mixed, and carry portions of trees, houses, and other debris. Extremely rapid landslides move at speeds in excess of 10 feet/second, while extremely slow landslides may move less than 2 inches/year. Most landslides are quite small, although they may occur in clusters. A very large landslide may have a volume of more than 1 cubic kilometer (35 billion cubic feet, or one-third of a cubic mile), while a very small landslide may have a volume of less than 1,000 cubic feet. Although individual landslides are generally not as spectacular or as costly as some geophysical hazards, landslides are widespread and collectively cause significant economic loss, deaths, and injuries. The average annual number of lives lost worldwide in landslides is about 500, although several times during this century, landslides have claimed more than 10,000 lives.

Landslides can be isolated, or occur in conjunction with earthquakes, volcanic eruptions, and floods.

Examples of Landslide Disasters. Some landslides are truly catastrophic. In 1920, earthquake-triggered landslides in Kansu Province, China, killed approximately 100,000 people. In 1949, an earthquake in the Tien Shan Mountains of Soviet Tadzhikistan triggered a series of massive landslides and debris flows that buried some 33 population centers, killing an estimated 12,000 to 20,000 people. In 1963, a massive high speed rockslide slid into the Vaiont Reservoir in Italy, and sent a wave of water more than 300 feet over the crest of the dam into the valley below, destroying five villages and killing more than 2,000 people. In 1962 and 1970, destructive debris avalanches occurred on the slopes of Mt. Huascaran in the Peruvian Andes. The 1962 landslide began as an ice avalanche from a glacier high on the north peak and soon became a mixture of water, ice, rock, and soil that roared through mountain villages, killing 4,000 to 5,000 people. The 1970 landslide was an earthquake-triggered avalanche consisting of 50 to 100 million cubic meters of granite blocks, ice, snow, and mud moving at about 200 miles/hour (300 feet/second). It covered a larger area than the 1962 slide, burying two towns and killing more than 18,000 people. In 1985, a mudslide caused by eruption of the Nevado del Ruiz volcano obliterated the town of Armero, Colombia, killing more than 20,000 people.

Most landslides are not of this catastrophic scale. Since they are primarily a mountain phenomenon, many occur in sparsely populated areas. Typical landslide disasters usually cause between 10 and 1,000 deaths. In 1974, one of the largest landslides in recorded history occurred in the Peruvian Andes. It dammed a river, created a temporary lake 19 miles long and as much as 550 feet deep, and killed 450 people. In 1983, heavy rain in Nagasaki and northern Kyushu, Japan, caused 5,000 landslides and debris flows, killing more than 300 people.

Two of the largest landslides in recent history caused very few deaths. The 1911 Pamir landslide in Soviet Tadzhikistan caused fewer than 100 deaths because the area was so sparsely populated. The rockslide and debris avalanche that accompanied the eruption of Mount St. Helens in 1980 killed fewer than 10 people, despite its high speed, broad extent, and burial of numerous roads, bridges, and buildings. Fortunately, most of the local population had been warned of the impending eruption and had evacuated.

Landslides can occur on artificial slopes. In 1966, a landslide on a coal waste tip killed 144 people in Aberfan, Wales. In Buffalo Creek, West Virginia, in 1972, heavy rain caused slope failure on a mine slag dam composed of three coal refuse impoundments, releasing a 30 foot wave of water. This became a debris flow that