Chapter 2

ROBERT L. SCHUSTER

SOCIOECONOMIC SIGNIFICANCE OF LANDSLIDES

1. INTRODUCTION

Landslides have been recorded for several centuries in Asia and Europe. The oldest landslides on record occurred in Honan Province in central China in 1767 B.C., when earthquake-triggered landslides dammed the Yi and Lo rivers (Xue-Cai and An-ning 1986).

The following note by Marinatos may well refer to a catastrophic landslide resulting in serious social and economic losses:

> In the year 373/2 B.C., during a disastrous winter night, a strange thing happened in central Greece. Helice, a great and prosperous town on the north coast of the Peloponnesus, was engulfed by the waves after being leveled by a great earthquake. Not a single soul survived. (Marinatos 1960)

Research by Marinatos indicated that Helice probably was engulfed as the ground slipped toward the sea a distance of about 1 km. Seed (1968) concluded that this was a major landslide, resulting from soil liquefaction caused by the earthquake.

Slope failures have caused untold numbers of casualties and huge economic losses. In many countries, economic losses due to landslides are great and apparently are growing as development expands into unstable hillside areas under the pressures of expanding populations. In addition to killing people and animals (both livestock and wildlife), landslides destroy or damage residential and industrial developments as well as agricultural and forest lands and negatively affect water quality in rivers and streams.

Landslides are responsible for considerably greater socioeconomic losses than is generally recognized; they represent a significant element of many major multiple-hazard disasters. Much landslide damage is not documented because it is considered to be a result of the triggering process (i.e., part of a multiple hazard) and thus is included by the news media in reports of earthquakes, floods, volcanic eruptions, or typhoons, even though the cost of damage from landslides may exceed all other costs from the overall multiple-hazard disaster. For example, it was not generally recognized by the media that most of the losses due to the 1964 Alaska earthquake resulted from ground failure rather than from shaking of structures.

Government agencies and those who formulate policy need to develop a better understanding of the socioeconomic significance of landslides. That knowledge will allow officials at all levels of government to make rational decisions on allocation of funds needed for landslide research; for avoidance, prevention, control, and warning; and for postfailure repair and reconstruction.

2. FUTURE LANDSLIDE ACTIVITY

In spite of improvements in recognition, prediction, mitigative measures, and warning systems,

worldwide landslide activity is increasing; this trend is expected to continue in the 21st century. The factors causing this expected augmented activity are

1. Increased urbanization and development in landslide-prone areas,
2. Continued deforestation of landslide-prone areas, and
3. Increased regional precipitation caused by changing climate patterns.

2.1 Increased Urbanization and Development

Population pressures are increasing in most of the world today and have resulted in rapid urbanization and development. For example, in the United States the land areas of the 142 cities with populations greater than 100,000 increased by 19 percent in the 15-year period from 1970 to 1985. Legget (1973) estimated that by the year 2000, 360 000 km^2 in the 48 conterminous United States will have been paved or built upon. This is an area about the size of the state of Montana. As a result of these population pressures, human activities have disturbed large volumes of geologic materials in housing development and in construction of industrial structures, transportation routes and facilities, mines and quarries, dams and reservoirs, and communications systems. Because of the huge extent of these activities, they increasingly have expanded into landslide-prone areas; thus, these developments have been a major factor in the recent increase in damaging slope failures.

In other countries, particularly developing countries, this pattern is being repeated, but with even more serious consequences. As development occurs, more and more of it is on hillside slopes that are susceptible to landsliding. All predictions are that worldwide slope distress due to urbanization and development will accelerate in the 21st century.

Population pressures are also causing increased landslide losses in other ways. An obvious example is the necessary construction of transportation facilities required by expanding populations. In landslide-prone areas, these facilities are often at risk.

2.2 Continued Deforestation

In many of the developing nations of the world, forests are being destroyed at ever-increasing rates. Removal of forest cover increases flooding, erosion, and landslide activity. Deforestation, which is expected to continue unimpeded into the 21st century, is causing serious landslide problems in many of these countries, Nepal being the best-documented example. According to the World Resources Institute (*Facts on File Yearbook* 1990), approximately 15 to 20 million ha of tropical forest is currently being destroyed annually, an area the size of the state of Washington.

2.3 Increased Regional Precipitation

For a period of about 3 years in the early 1980s, El Niño caused regional weather changes in western North America that resulted in much heavier-than-normal precipitation in mountainous areas. One of the results was a tremendous increase in landslide activity in California, Colorado, Nevada, Oregon, Utah, and Washington. Climatologists do not know what to expect from future El Niños except that these climatic perturbations will also change climate patterns, certainly increasing precipitation in some areas of the world and thus causing landslide activity.

Scientists do not know what to expect from the much-publicized greenhouse effect either. Will it cause an overall increase in temperature and decrease in precipitation (as occurred in central North America in the late 1980s) or will it disrupt climate patterns, resulting in drought in some areas and increased precipitation in others (as occurred in western North America at the same time)? If areas that are prone to landsliding are subjected to greater-than-normal precipitation, they are apt to experience increased landslide activity.

3. ECONOMIC LOSSES CAUSED BY LANDSLIDES

In this discussion of the expense of landslides at national and local levels, the costs are given in U.S. dollars for the time at which they were originally determined, except where noted. In addition, the original values adjusted to 1990 U.S. dollars are presented in parentheses; the adjustments were made on the basis of yearly cost-of-living indexes for the United States (Council of Economic Advisers 1991).

3.1 Categories of Damage Costs

There are significant advantages to the ability of government officials, land use planners, and others to distinguish between direct and indirect landslide costs and to determine whether these costs affect public or private entities.

3.1.1 Direct Versus Indirect Costs

Landslide costs include both direct and indirect losses that affect public and private properties. Direct costs are the repair, replacement, or maintenance resulting from damage to property or installations within the boundaries of the responsible landslides or from landslide-caused flooding. An outstanding example of direct costs resulting from a single major landslide is the $200 million ($260 million) loss due to the 1983 Thistle, Utah, landslide (University of Utah 1984). This 21-million-m^3 debris slide (Figure 2-1) severed major transportation arteries, and the lake it impounded inundated the town of Thistle and railroad switching yards.

All other costs of landslides are indirect. Examples of indirect costs are

1. Loss of industrial, agricultural, and forest productivity and tourist revenues as a result of damage to land or facilities or interruption of transportation systems;
2. Reduced real estate values in areas threatened by landslides;
3. Loss of tax revenues on properties devalued as the result of landslides;
4. Measures to prevent or mitigate additional landslide damage;
5. Adverse effects on water quality in streams and irrigation facilities outside the landslide;
6. Loss of human or animal productivity because of injury, death, or psychological trauma; and
7. Secondary physical effects, such as landslide-caused flooding, for which losses are both direct and indirect.

Indirect costs may exceed direct costs; unfortunately, however, most indirect costs are difficult to evaluate and thus are often ignored or, when estimated, are too conservative.

3.1.2 Public Versus Private Costs

Of possibly greater importance than whether costs are directly or indirectly attributable to a landslide is attribution of the costs on the basis of who is actually faced with the losses. On this basis, landslide losses can be separated into costs to public

FIGURE 2-1
Aerial view in September 1983 of April 1983 Thistle debris slide, Utah, showing Thistle Lake, which was impounded by the landslide; realignment of Denver and Rio Grande Western Railroad in lower center; and large cut for rerouting US-6/50 in extreme lower left.

and private entities (Fleming and Taylor 1980). The possibility of a major landslide that could destroy port facilities and create a wave that might inundate downtown Kodiak, Alaska, is an example of a landslide threat during the 1970s and 1980s that is alleged to have caused indirect costs relating to planning for expansion of the port area (Schuster and Fleming 1988).

Public costs are those that must be met by government agencies; all others are private costs. The largest direct public costs commonly have been for rebuilding or repairing government-owned highways and railroads and appurtenant structures such as sidewalks and storm drains. Other examples of direct public costs resulting from landslides are those for repair or replacement of public buildings, dams and reservoirs, canals, harbor and port facilities, and communications and electrical power systems. Indirect public costs include losses of tax revenues, reduction of potential for productivity of government forests, impact on quality of sport and commercial fisheries, and so forth. An interesting example of indirect public costs due to the impact on fisheries of mass movement and erosion was presented by a study of Tomiki Creek, Mendocino County, California, in the early 1980s. This study found that production of steelhead trout and salmon in Tomiki Creek was reduced 80 percent by landslide, gully, and streambank erosion, resulting in a continuing loss in fisheries potential of $844,000 ($1 million) annually (Soil Conservation Service 1986). In the case of major landslide events, public costs are sustained by all levels of government from federal to local and often by more than one agency within a particular level.

Private costs consist mainly of damage to real estate and structures, either private homes or industrial facilities. In the United States, most railroads are privately owned. Severe landslide problems can result in financial ruin for affected private property owners because of the general unavailability of landslide insurance or other means to distribute damage costs.

3.2 Difficulties in Determining Losses

Although it often is possible to determine the costs of individual landslides, reliable estimates of the total costs of landslides of large geographic entities, such as nations, provinces and states, or even counties, are generally very difficult to obtain. In the public sector, accounting for landslide costs is often lost within general maintenance operations; this seems to be particularly common for transportation agencies. To separate out landslide costs is in itself a costly and complicated operation. In the private sector, the costs incurred by natural hazards are often downplayed as much as possible in order to minimize negative publicity for the company involved.

Landslide cost data commonly are more readily available for industrialized nations than for developing countries. For this reason, most of the economic data presented here are for industrialized countries, such as the United States, Japan, and those in Europe. However, because the severity of the worldwide landslide problem is becoming more widely recognized, the collection of economic data for landslide damages is spreading to all affected nations.

3.3 Losses in the United States

Landslides occur in every one of the United States and are widespread in the island territories of American Samoa, Guam, Puerto Rico, and the U.S. Virgin Islands (Committee on Ground Failure Hazards 1985). They constitute a significant hazard in more than half the states, including Alaska and Hawaii. In the conterminous United States, the areas most seriously affected are the Pacific Coast, the Rocky Mountains, and the Appalachian Mountains (Figure 2-2).

Most of the loss estimates presented here for the United States can be related directly to other industrialized nations with similar terrains and mixes of urban and rural habitats. However, the costs are somewhat higher than might be expected in developing countries, where property and labor values commonly are lower than they are in the United States and other industrialized nations.

Although no cost-reporting mechanism is in use nationally, the U.S. Geological Survey has developed a method for estimating the cost of landslide damage (Fleming and Taylor 1980). Application of this method to smaller geographic areas has suggested that incomplete and inaccurate records have resulted in reported costs that are much lower than those actually incurred. It also appears that losses are on the increase in most regions in spite of an improved understanding of landslide processes and a rapidly developing technical capability for

FIGURE 2-2
Map showing relative potential for landsliding in conterminous United States (modified from Radbruch-Hall et al. 1982).

landslide prediction and mitigation (Committee on Ground Failure Hazards 1985).

In perhaps the first national estimation of U.S. landslide costs, Smith (1958) reported that "the average annual cost of landslides in the U.S. runs to hundreds of millions of dollars," which was probably a realistic figure for that time. However, in the 37 years since Smith assembled his cost data, inflation, residential and commercial development that continues to expand into landslide-susceptible areas, and the use of larger cuts and fills in construction have increased the annual costs of landslides.

On the basis of their analysis of landslide loss data for southern California, Krohn and Slosson (1976) established a figure of $20 per year in 1971 dollars ($46 per year) for damage to each private home in that area. Extrapolating this figure to the estimated 20 million people who at that time resided in areas of the United States with moderate to high landslide susceptibility, they estimated the annual national costs of landslides to private dwellings at about $400 million in 1971 dollars ($1.3 billion). This figure did not include indirect costs or costs to public property, forest or agricultural lands, mines, transportation facilities, and so on. Also in 1976, Jones (at the National Workshop on Natural Hazards, Institute for Behavioral Sciences, University of Colorado, Boulder) estimated that direct costs of landslides for buildings and their sites were about $500 million ($1.2 billion) annually. These estimates were substantiated by Wiggins et al. (1978), who arrived at a total of $370 million in 1970 dollars ($1.2 billion) for annual losses to buildings in the United States due to landslides.

Using the above information, previously unpublished data, inflationary trends, and rough estimates of indirect costs, Schuster (1978) estimated that the total direct and indirect costs of slope failures in the United States exceeded $1 billion per year. Schuster and Fleming (1986) believed that by 1985 this annual figure had increased to nearly $1.5 billion ($1.8 billion), most of the increase being due to inflation. In 1985 the National Research Council (Committee on Ground Failure Hazards 1985) estimated that annual landslide costs in the United States were about $1 billion to $2 billion ($1.2 billion to $2.4 billion), a figure of about $5 to $10 per capita per year ($6 to $12 per capita per year) averaged over the entire nation. Slosson (1987) estimated that total landslide losses in the state of California alone were as high as $2 billion for the decade from 1977 to 1987.

Brabb (1984) used unpublished data based on interviews of personnel from state highway departments and geological surveys to come up with a much lower figure, about $250 million per year (about $315 million per year). However, Brabb's study did not include indirect costs or the costs of infrequent catastrophic events, such as those for landslides from the 1964 Alaska earthquake, because of the difficulty in establishing initial costs and recurrence intervals (Brabb 1989). In addition, interviews of this type often underestimate true costs because the personnel providing the information do not know the total landslide costs within their areas of jurisdiction. Such costs can be determined with reasonable accuracy only by means of rigorous study programs that include delineation of costs to private corporations and property owners.

Total annual costs of landslides for transportation systems in the United States are difficult to determine because of the difficulty in analyzing the following:

1. Smaller slides that are routinely corrected by maintenance forces;
2. Slides on non-federal-aid public highways and roads;
3. Slides on privately owned transportation routes, such as railroads; and
4. Indirect costs related to landslide damage, such as traffic disruptions and delays, inconvenience

to travelers and shippers, and analysis and prevention of landslides.

In spite of these handicaps, attempts were made during the 1970s to estimate annual landslide losses to the U.S. highway system. Chassie and Goughnour (1976a, 1976b) reported on a survey by the Federal Highway Administration in which it was indicated that approximately $50 million per year ($115 million per year) was spent at that time to repair landslides on the federally financed portion of the national highway system. This system includes federal and state highways but not most county and city roads and streets, private roads and streets, or roads built by other federal agencies, such as the U.S. Forest Service, the Bureau of Land Management, or the National Park Service. If indirect costs, costs to non-federal-aid highways, and the other factors noted above were added, Chassie and Goughnour (1976b) estimated that $100 million ($230 million) was a conservative value of the annual landslide damage to highways and roads in the United States in the 1970s.

The 1976 Federal Highway Administration survey of landslide costs for U.S. highways was duplicated by Walkinshaw (1992), who obtained repair and maintenance costs for landslide damage to 1.3 million km of state highways for the 5-year period from 1986 to 1990. Walkinshaw found that the total average annual cost of contract landslide repairs on state highways for this period was $65.4 million (Figure 2-3), and annual average landslide maintenance costs (repairs by highway department maintenance forces) were reported as $41.4 million, for a total average annual direct cost of nearly $106 million, a figure nearly equal to the 1990 equivalent of $115 million that Chassie and Gougnour (1976b) found for annual repair and maintenance costs in the 1970s. Thus, direct landslide costs to highways have remained nearly constant (when noted in 1990 dollars) in spite of the near-completion of the Interstate highway construction program and drier-than-normal weather in the western United States during the 1986–1990 survey period.

It should be remembered that the cost figures presented in both the Chassie and Goughnour (1976b) and the Walkinshaw (1992) surveys do not represent total landslide costs, either direct or indirect, for the U.S. highway system. One deficiency of these surveys is that the state and federal highways for which the surveys were conducted represent only about 20 percent of the 6 239 000 km in the entire U.S. highway and road system. However, this 20 percent probably is subject to the major part of landslide costs because it has been constructed to higher standards than the rest of the system (i.e., larger cuts and fills were used).

Another deficiency of these surveys is that many state transportation departments do not maintain satisfactory inventories of their highway landslide maintenance costs. Several states that have kept good maintenance records (particularly Maine, West Virginia, Kentucky, Missouri, Texas, Colorado, and California) have found that the maintenance costs for landslides have exceeded their contract repair costs (Walkinshaw 1992). California distinguished itself by reporting the highest annual cost for landslide maintenance of all the states—more than $15 million per year, even during 5 years of well-below-normal precipitation.

Such landslide cost surveys have not attempted to determine indirect costs of landslides. A cost item that often is large but is extremely difficult to determine accurately is the indirect cost of loss of business in communities whose commerce is hindered by the closure of transportation routes because of landslides. An example of the magnitude of such indirect costs in relationship to direct actual repair costs was provided by the 1983 landslide closure of US-50 by landslides both west (in California) and east (in Nevada) of south Lake Tahoe. The total cost of repairs to the heavily traveled highway was $3.6 million ($4.7 million) (Walkinshaw 1992), but the estimated economic

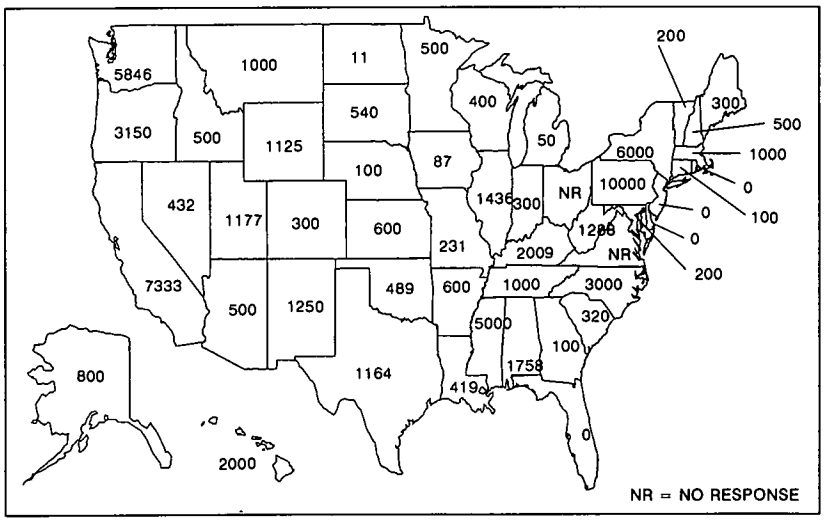

FIGURE 2-3
Average annual costs (in thousands of dollars) of contracted highway repairs on U.S. state highway systems for 1986–1990 (Walkinshaw 1992).

FIGURE 2-4
(top right)
August 1989 rock fall from gneiss cliff onto Washington State Highway 20, North Cascades National Park, blocking highway for about 2 weeks (note tunnel portal behind debris); example of highway landslide for which indirect costs due to forced traffic diversion are difficult to determine.

FIGURE 2-5
(top far right)
Damage to railroad line in Olympia, Washington, caused by slope failure after 1965 Seattle-Tacoma earthquake.
G. W. THORSEN, DIVISION OF GEOLOGY AND EARTH RESOURCES, WASHINGTON DEPARTMENT OF NATURAL RESOURCES

FIGURE 2-6
(bottom)
Landslide resulting in derailment of *California Zephyr* passenger train near Granby, Colorado, in April 1985. Small landslide started as earth slide through base of railway embankment in middle background and rapidly moved about 70 m as debris flow, partially damming Fraser River in foreground.

loss to the area from 2 ½ months of access disruption and the resulting loss of tourist revenues was $70 million ($92 million) (*San Francisco Chronicle* 1983), nearly 20 times as much as the direct expenditures for repair. A lesser, but more common, example is the August 1989 rock fall (Figure 2-4) that blocked Washington State Highway 20 in North Cascades National Park for 2 weeks. During this period traffic from the northern Puget Sound area to north-central Washington had to be directed farther south to US-2 and Interstate 90 at a cost in both mileage and time.

There is no firm information on landslide losses by U.S. railroads because nearly all U.S. railroads are private corporations that do not commonly release such data. However, it is estimated that direct losses to railroads from landslides in the Rocky Mountain states for the period 1982–1985, during which precipitation was much greater than normal, exceeded $100 million ($120 million). During periods of normal precipitation, landslide losses to U.S. railroads are much lower than they were during this unusual period. An economic impact analysis by the University of Utah (1984) noted that the largest single loss caused by the 1983 Thistle, Utah, landslide (Figure 2-1) was the $81 million ($107 million) in revenue lost by the Denver and Rio Grande Western Railroad (D&RGW) because of temporary closure of their main line by the slide. Figures 2-5 and 2-6 show examples of the effects of landslides on railway operations.

3.4 Losses in Other Nations

Japan probably has the dubious honor of being the nation with the world's greatest total landslide costs. In 1982, N. Ohhira (personal communication, Director-General, Japanese National Research Center for Disaster Prevention, Tsukuba City) noted that annual losses in Japan totaled about $1.5 billion ($2 billion), a figure comparable with that for the United States. However, on the basis of data provided by the Japanese Ministry of Construction, Oyagi (1989) estimated that the costs of landslide control works constructed in Japan in 1987 and 1988 were in excess of $4 billion per year ($4.4 billion per year). Similarly, Moriyama and Horiuchi (1993) and Nishimoto (1993) reported a total cost for Japanese landslide control works in fiscal year 1992 of approximately $4.7 billion. Of this figure, $3.4 billion went to the Sabo erosion control works (mainly check dams to prevent debris flow damage), $50 million for "landslide prevention works," and $850 million for "slope failure remedies" (all three of which are considered here as landslide control works). An additional $54 million was spent to control snow avalanches.

The Alpine nations of western Europe, particularly Italy, Austria, Switzerland, and France, have been subject to significant landslide activity from the beginning of recorded history. For the Alpine countries, Eisbacher and Clague (1984) described 137 landslide case histories that represent "the most interesting, costly and tragic mass movements witnessed in 2000 years of Alpine settlement." The unpublished results of a 1976 United Nations Educational, Scientific, and Cultural Organization (UNESCO) survey indicated that annual landslide losses in Italy were about $1.14 billion ($2.6 billion) (M. Arnould, personal communication, 1982, Ecole Nationale Supérieure des Mines, Paris). No similar information has been encountered for landslide costs of other Alpine nations, but it is estimated that they would be somewhat lower than those for Italy.

On the basis of estimated annual landslide damages of $100 million ($135 million) to 10 000 km of highways and roads in the hilly and mountainous topography of northern India, Mathur (1982) arrived at an annual cost for landslide damages of nearly $1 billion ($1.35 billion) for the total 89 000 km of roads in this landslide-prone area. In addition to the commonly used reconstruction and maintenance costs, Mathur's estimates included indirect costs, such as loss of tourist trade, loss of person-hours and vehicle-hours resulting from road blockages, and failure of communications, that may not have been included in the estimates for the United States, Japan, and Italy. Besides Mathur's cost data, Chopra (1977) noted that catastrophic damage to roads in north Bengal and Sikkim occurred in 1968 and 1973; restoration was estimated to cost $14 million ($53 million) and $8 million ($24 million), respectively.

Thus, landslide costs (direct plus indirect) in the United States, Japan, Italy, and India seem to be roughly comparable, somewhere between $1 billion per year and $5 billion per year for each country. Although there have been few other published estimates of landslide costs, the data that are available indicate that landslide costs for other countries are considerably lower. Li (1989) reported that annual losses for China are about $500 million. Ayala and Ferrer (1989) arrived at a figure of $220 million for yearly landslide costs in Spain. S. G. Evans (personal communication, 1989, Geological Survey of Canada, Ottawa) estimated that annual landslide costs for Canada are about $50 million. In Hong Kong, a small, densely populated area with serious landslide problems, the government spends $25 million per year for landslide studies and remedial works (Brand 1989). Hawley (1984) estimated that annual landslide costs for New Zealand are approximately $12 million ($15 million). In 1982, Swedish costs were about $10 million per year to $20 million per year ($13 million per year to $27 million per year) (Cato 1982), and those for Norway are estimated at $6 million per year (Gregersen and Sandersen 1989).

For the industrialized nations of central and eastern Europe, little information is available on national landslide costs. However, it is well known that several republics of the former Soviet Union have serious landslide problems in their far-ranging hill and mountain areas. Because of the huge area involved, total landslide costs in the republics of the former Soviet Union are estimated to be on the same order as those previously given for China. As an example of these costs, Khegai and Popov (1989) estimated that landslide activity (mainly debris flows) in the vicinity of Alma-Ata, Kazakhstan, has caused total damage of about $500 million in the past few decades. The central European mountains of Czechoslovakia, Poland, Hungary, Romania, and Bulgaria have also proved to be susceptible to landsliding (Kotarba 1989), but no cost figures have been published for these countries.

Very few national landslide cost estimates are available for developing countries because little research has been done on this subject. However, landslide disasters are common in many of these countries, particularly in mountainous areas. Especially hard hit have been the Himalayan and Andean nations and the island nations around the Pacific Rim of Fire, particularly Papua New Guinea (Figure 2-7), Indonesia, the Philippines, and Taiwan. For example, Charma (1974) reported that landslides in Nepal have killed hundreds of people, displaced more than 1,000 families, and cost hundreds of thousands of dollars in damage, much of which has been to roads and highways. For developing countries in these areas, landslide losses probably represent a larger part of the gross national product than for the industrialized nations discussed earlier.

3.5 Losses in Smaller Geographic Areas

In the United States there was little documentation of major landslide damages until the early

FIGURE 2-7
Bairaman River rock slide–debris avalanche, 1985, triggered by magnitude 7.1 earthquake on island of New Britain, Papua New Guinea. This 180-million-m^3 landslide caused little direct financial loss because it occurred in unpopulated mountainous area. However, it formed 210-m-high blockage of Bairaman River. When this natural dam failed 14 months after quake, huge flood destroyed village of Bairaman, 40 km downstream. Residents of village had been evacuated before dam breached; consequently, no lives were lost.
P. LOWENSTEIN, GEOLOGICAL SURVEY OF PAPUA NEW GUINEA

part of the 20th century. Although economic data are sketchy, landslides caused by the 1906 San Francisco earthquake had a significant socioeconomic effect on northern California, an effect that received little publicity because of the enormity of direct earthquake damages in the city of San Francisco itself. The 1906 earthquake triggered ground failures (primarily slope failures) over a 600-km zone extending along the northern California coast from Eureka on the north to southern Monterey County and as far as 100 km inland (Youd and Hoose 1978). Hillside landslides triggered by the earthquake were too numerous for documentation of each occurrence. Many were in unpopulated areas; however, where slope failures impinged on human works, the results were generally disastrous. For example, 10 men were killed and two lumber mills destroyed by landslides in the Santa Cruz Mountains, and 5 km of the Ocean Shore Railroad was destroyed along the coastal bluffs south of San Francisco. Roadways, bridges, pipelines, and buildings suffered considerable damage from lateral spreads. Pipeline breaks were particularly critical in San Francisco, cutting off the water supply to a city that was soon devastated by fire.

Some 500 reservoir-induced landslides along the shore of Franklin D. Roosevelt Lake, the reservoir impounded by Grand Coulee Dam on the Columbia River in Washington State, caused at least $20 million (about $150 million) in damages between 1934 and 1952 (Jones et al. 1961). Landslide activity along the shores of Lake Roosevelt has continued since then, particularly in 1969 and 1974 when the reservoir was drawn down 40 m for construction of the Grand Coulee Dam third power plant (Schuster 1979).

The most economically devastating landslides in the United States in recent decades were those triggered by the 1964 Alaska earthquake, the 1980 landslides in southern California, the 1982 landslides in the San Francisco Bay area, and the 1983–1984 landslides in Utah and surrounding states. Youd (1978) estimated that ground failure caused 60 percent of the $300 million ($1.26 billion) total damage from the 1964 Alaska earthquake; nearly all of the ground failure consisted of landslides, including lateral spreads. Five major landslides caused about $50 million ($210 million) in damage to nonmilitary facilities in Anchorage, Alaska's largest city (Figure 2-8). The total damage to Alaskan highways, railways, and bridges caused by lateral spreads also amounted to about $50 million. Flow failures in the coastal communities of Valdez (Figure 2-9), Seward, and Whittier carried away port facilities that originally cost about $15 million ($63 million).

Within the United States greater effort at detailing the costs of slope movements has been expended in California than in any other state.

FIGURE 2-8
Wreckage of Government Hill School, Anchorage, Alaska, which was destroyed by 700 000-m^3 landslide triggered by March 1964 earthquake (Hansen 1965). There were no casualties because earthquake occurred on Sunday when school was not in session. Graben 4 m deep in foreground is at head of slide.
W.R. HANSEN, U.S. GEOLOGICAL SURVEY

Landslide-causing storms have plagued southern California for the past three decades. Exceptional landslide activity occurred in 1951–1952, 1956, 1957–1958, 1961–1962, 1968–1969, 1977–1978, 1979–1980, and 1982. The Portuguese Bend landslide (Palos Verdes Hills, California) was estimated to have cost in excess of $10 million ($45 million) in damages to roads, homes, and other structures between 1956 and 1959 (Merriam 1960). It was necessary to raze 127 residential dwellings and a privately owned recreational club that were located on the slide. Subsequent litigation resulted in an award of approximately $9.5 million ($41 million) by the County of Los Angeles to property owners in the affected area on the grounds that road construction by the county was responsible for initiating the failure (Vonder Linden 1989).

Since the time of the Portuguese Bend landslide, there have been many costly landslides in southern California. The 1978 Bluebird Canyon landslide (Figure 2-10) caused an estimated direct loss of $15 million ($30 million) to private property in Laguna Beach, south of Los Angeles (Tan 1980). The estimated total losses in the six southern counties of California in 1980 due to all types of landslides caused by heavy winter rainfall approximated $500 million ($800 million) (Slosson and Krohn 1982). As another example of southern California slope failure costs, a study by the U.S. Geological Survey during the winter rainy seasons of 1978–1979 and 1979–1980 documented 120 landslides in San Diego County, which caused damages of about $19 million ($34 million) (Shearer et al. 1983).

The most recent major losses in southern California were caused by the Big Rock Mesa landslide along the Malibu coast west of Los Angeles. This large creeping mass movement, which began in the late summer of 1983 and threatened "to dump 120 acres overlooking the Pacific Coast Highway into the ocean" (*Los Angeles Times* 1984), by March 1984 resulted in condemnation of 13 houses and threatened more than 300 others. The individual homes ranged in value from $400,000 to more than $1 million ($500,000 to more than $1.25 million). During 1984 many lawsuits related to this landslide were filed by property owners against Los Angeles County and a number of consultants. According to a deputy county counsel, the total of legal claims against Los Angeles County as a result of the Big Rock Mesa landslide by July 1984

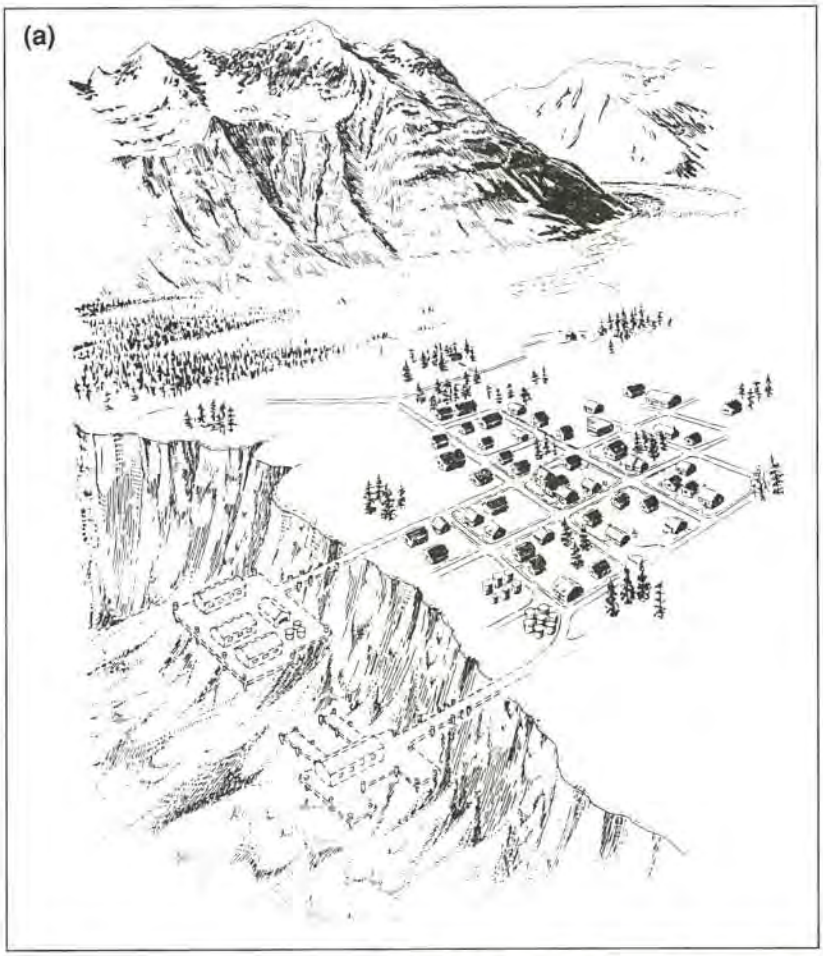

FIGURE 2-9
(*a*) Destruction of port facilities at Valdez, Alaska, by submarine landslide triggered by March 1964 earthquake (Coulter and Migliaccio 1966). Dashed lines indicate dock area destroyed by slide. DAVID LANEVILLE, U.S. GEOLOGICAL SURVEY (*b*) Valdez dock area after reconstruction, September 1965. U.S. BUREAU OF LAND MANAGEMENT

FIGURE 2-10 Damage caused by 1978 Bluebird Canyon landslide, Laguna Beach, California, which destroyed 25 homes, parts of three streets, and area's public utilities. WOODY HIGDON, COURTESY OF LEIGHTON AND ASSOCIATES, INC.

was more than $500 million ($630 million) (Association of Engineering Geologists 1984).

The San Francisco Bay area of northern California also has been hit hard by landslides. In a classic study of landslide costs in that area, Taylor and Brabb (1972) documented losses amounting to $25 million ($90 million) in the nine Bay-area counties for the rainy season of 1968–1969, a large expense for the relatively small area involved. Of this total, about $10 million ($36 million) consisted of loss or damage to public property, mainly for relocation or repair of roads and utilities; about $9 million ($32 million) was for loss or damage to private property, primarily because of reduced market value; and about $6 million ($21 million) consisted of miscellaneous costs that could not be classified in either the public or private sector. The intense storms of January 1982 in the San Francisco Bay area triggered thousands of debris flows and a few large landslides. About 30 people were killed and hundreds left homeless in this catastrophe. About 6,500 homes and 1,000 businesses were damaged or destroyed. Most of the fatal or damaging landslides were debris flows. Creasey (1988) documented total direct costs of the landslides as being in excess of $66 million ($90 million). In the wake of these damages, 930 lawsuits and claims in excess of $298 million ($404 million) were filed against city and county agencies in the San Francisco Bay region as of May 1982 (Smith 1982), an amount considerably greater than the total property losses.

In 1980 a massive rock slide–debris avalanche (Figure 2-11) with a volume of 2.8 km^3 descended at high velocity from the north slope of Mount St. Helens, Washington, as a result of the eruption of the volcanic peak (Voight et al. 1983). The debris avalanche traveled about 22 km westward, burying about 60 km^2 of the valley of the North Fork Toutle River under poorly sorted earth-and-timber debris. It destroyed nine highway bridges, many kilometers of highways and roads, and numerous private and public buildings (Schuster 1983). The debris avalanche also formed several new lakes by damming the North Fork Toutle River and its tributaries. These lakes and their natural dams posed downstream hazards because of the possibility of failure of the natural dams, which could have resulted in catastrophic downstream flooding. The largest landslide-dammed lake is 260-million-m^3 Spirit Lake, which was prevented from overtopping its natural dam by a bedrock drainage tunnel 2.9 km long that was completed in 1985 at a cost of $29 million ($35 million) (Sager and Budai 1989).

Mud flows continued downstream for 95 km beyond the toe of the debris avalanche, modifying a total of more than 120 km of river channel, including the Toutle River and sections of the Cowlitz and Columbia rivers (Schuster 1983). The mud flows destroyed or badly damaged about 200 homes on the floodplain of the Toutle River. About half of the 27 km of Washington State

FIGURE 2-11 Mount St. Helens debris avalanche in valley of North Fork Toutle River, May 1980: view east from distal margin of avalanche toward devastated cone of volcano. R. M. KRIMMEL, U.S. GEOLOGICAL SURVEY

Highway 504 along the Toutle River was buried under as much as 2 m of sediment (Figure 2-12). Mud flows also buried many kilometers of private logging roads and county roads and destroyed 27 km of logging railway (Figure 2-13). The mud flows and giant logjams they were carrying destroyed or badly damaged 27 highway and railroad bridges (Figure 2-14).

Abnormally high precipitation in 1982–1984 caused thousands of landslides in the western mountain areas of the United States. Anderson et al. (1984) estimated that total direct costs of landslides in the state of Utah in spring 1983 exceeded $250 million ($330 million). Estimates of direct costs of the 1984 Utah landslides were as high as $50 million ($63 million) (B.N. Kaliser, personal communication, 1984, Utah Geological and Mineral Survey, Salt Lake City). The April 1983 Thistle debris slide (Figure 2-1), Utah's single most destructive slope failure, and the lake it formed by damming the Spanish Fork River severed three major transportation arteries: US-6/50, US-89, and the main transcontinental line of the Denver and Rio Grande Western Railroad (D&RGW) (Kaliser 1983). The D&RGW spent about $40 million ($53 million) to reestablish its line outside the devastated area, mostly to construct a twin-bore tunnel about 900 m long that bypassed the landslide and lake (Malone 1983). Before the lake was drained, it inundated the town of Thistle, resulting in destruction of 10 homes, 15 businesses, and D&RGW switching yards.

FIGURE 2-14
Remains of steel-girder bridge across Toutle River, Washington State, May 1980. Bridge was destroyed by mud flow associated with eruption of Mount St. Helens.

An economic impact analysis prepared by the University of Utah (1984) evaluated direct and indirect costs of the Thistle landslide. The direct costs totaled $200 million ($260 million). In addition, numerous indirect costs were reported; most of these involved temporary or permanent closure of highway and railroad facilities to the detriment of local coal, uranium, and petroleum industries; several types of businesses; and tourism. A branch line of the D&RGW that joined the main line at Thistle was closed by the lake and has not been reopened. Numerous private enterprises, six communities, and two counties were directly affected by this railroad closure, and other businesses and communities were indirectly affected because of reduced production, unemployment, and reduced income. Of the jobs lost directly as a result of the Thistle landslide, 196 were abolished permanently. More than 2,500 jobs were temporarily lost in the mining industry alone. During 1983, unemployment in the two affected counties increased more than 300 percent. Perhaps the largest single loss due to the Thistle landslide was $81 million ($107 million) in revenue lost by the D&RGW in 1983 as a result of the slide. The indirect effects of the Thistle landslide disaster have produced temporary

FIGURE 2-12
(top left)
Mud flow from Mount St. Helens covering Washington State Highway 504 to depth of 2 m in valley of North Fork Toutle River. Mud flow material was easily removed from highway surface by means of front-end loaders.

FIGURE 2-13
(bottom left)
Railway cars and logs overturned by 1980 Toutle River mud flow, Washington State.

and permanent losses that may perhaps exceed the direct costs. Although there were no casualties in the Thistle landslide, it ranks as the most economically expensive individual landslide (in terms of both direct and total costs) in North America.

There have been few estimates of financial losses due to landslides in the eastern United States. However, studies of landslide costs in Pittsburgh, Pennsylvania, and Cincinnati, Ohio, indicate that costs in the Appalachian Mountains, and particularly in urban areas, are significant. Expenditures for landslide damages in Allegheny County (Pittsburgh), Pennsylvania, for the period 1970–1976 were estimated at about $4 million per year ($12 million per year) for an annual per capita outlay of about $2.50 ($7.00) (Fleming and Taylor 1980). In Hamilton County (Cincinnati), Ohio, landslide damage costs for the 6-year period from 1973 to 1978 averaged $5.1 million per year ($12.4 million per year), an annual per capita outlay of $5.80 ($14). Not included in this total was at least $22 million ($53 million) that was spent to stabilize a single landslide in Cincinnati (Fleming 1981).

With the exception of these estimates of landslide costs for Pittsburgh and Cincinnati, little attempt has been made to determine landslide losses for the eastern United States. The data for Pittsburgh and Cincinnati suggest that significant damages occur there each year as opposed to the western United States, where landslide activity is closely associated with years of above-average precipitation or with single high-intensity storms (Schuster and Fleming 1986). The general pattern of damages in areas susceptible to landsliding in the eastern United States is one of consistently large annual costs punctuated by a few years of extreme damages caused by severe hurricanes on the East Coast.

The many major slope failures that occurred during construction of the 12-km long Gaillard Cut in the Continental Divide segment of the Panama Canal (Lutton et al. 1979) constituted one of the world's most extreme cases of damage to a transportation system (Figures 2-15 and 2-16). Slope failures not only severely disrupted construction, delaying completion of the canal by nearly 2 years, but also caused closing of the canal on seven different occasions after it was opened to traffic in 1914. In 1915 the two largest landslides, the East and West Culebra slides, with volumes of 13 and 10 million m^3, respectively, occurred simultaneously, completely blocking the canal (Berman 1991). As noted by MacDonald (1942), "The confidence of the American people and its Congress was shaken by the delay in achieving continuous service." Although detailed costs of damages resulting from Panama Canal landslides from the construction period to present are not available, the following data published by the Panama Canal Company indicate the economic severity of the effects of the slope failures (MacDonald 1942):

1. During construction, excavation was disrupted for days and weeks at a time because landslides blocked haulage railroad tracks;
2. Steam shovels, locomotives, drilling equipment, railway cars, and other equipment were destroyed during construction (Figure 2-16);
3. Construction costs were millions of dollars higher than they would have been if the landslides had not occurred;
4. Between the beginning of construction and 1940, 57 million m^3 of landslide material was removed from the canal; and
5. Many millions of dollars in shipping tolls were lost by delay in opening the canal and by periods of enforced closure due to landslides.

Although landslides have not closed the canal since 1920, they still threaten navigation and pose a continuing and expensive maintenance problem for the Panama Canal Commission, which is now a binational agency representing the Republic of Panama and the United States. A 4.6-million-m^3 reactivation of the Cucaracha landslide (Figure 2-17) nearly closed the canal in 1986 (Berman 1991).

The original width of the channel in the Gaillard Cut was 91 m; by 1970 it had been widened to 152 m. By the mid-1980s the increase in large-beam ships proved to be an obstacle to navigation through the cut. Thus, in May 1991 the Panama Canal Commission implemented a widening program; the width of the channel is being increased to 192 m in the straight portions of the cut and to 213 to 223 m on the curves (Schuster and Alfaro 1992). Approximately 27×10 m^3 of material will be excavated, which could result in increased slope failure hazards. To reduce the risk, slopes are being geotechnically designed and drainage systems installed to alleviate the rainfall-induced pore pressures that cause the slopes to fail.

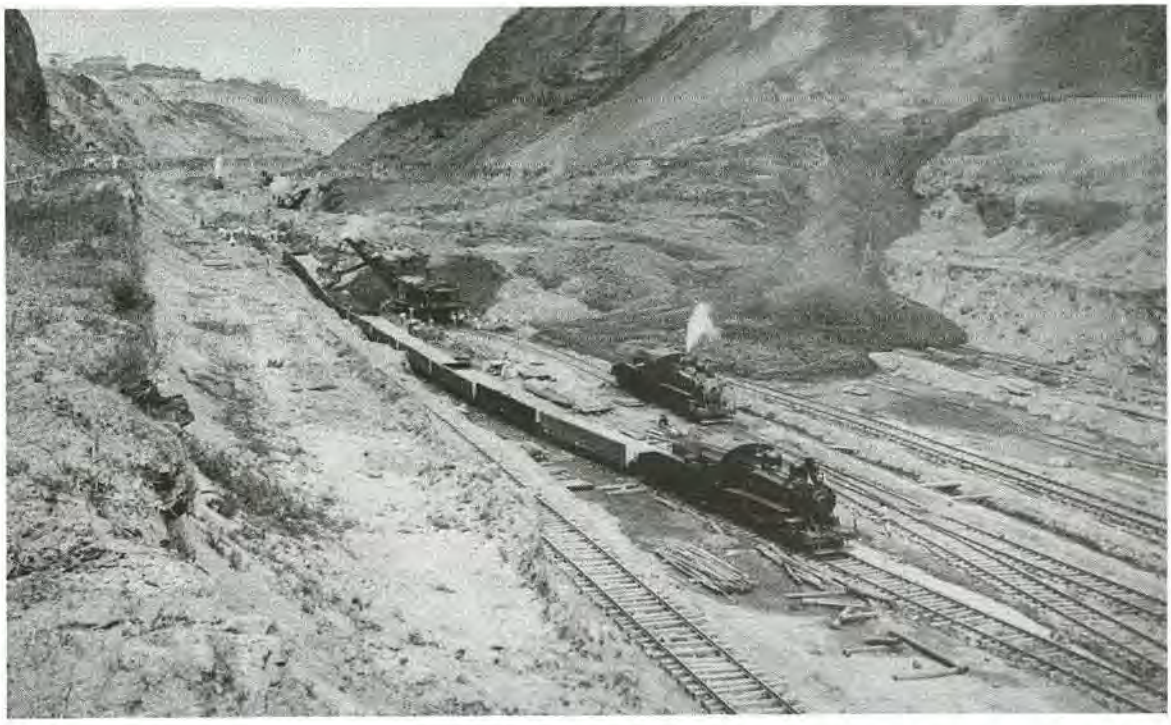

FIGURE 2-15
Cucaracha landslide, February 2, 1913, during construction of Gaillard Cut, Panama Canal (MacDonald 1942). Construction railroad tracks are on bottom of future canal. Activity of this 2.2-million-m^3 earth slide–earth flow continued during and after filling of canal.
COURTESY OF PANAMA CANAL COMMISSION

As much as 650 mm of torrential rain fell on parts of the island of Oahu, Hawaii, in 24 hr over New Year's Eve 1987–1988. Resultant flooding and debris flows caused an estimated $34 million in damages (Dracup et al. 1991). The Niu, Kuliouou, and Hahallone valleys were the most severely affected; most of the damage in these valleys was due to debris flows. In addition, the storm resulted in an estimated 10 to 15 soil slides in each of the valleys. Some of the slides caused heavy damage in residential areas. Total cost data are not available for these slides except for a state-sponsored residential subdivision in Kuliouou Valley, where a single slow-moving landslide severely damaged 17 family residences, which were replaced at a total cost of $5.7 million (*Honolulu Star-Bulletin* 1989).

Physical measures to protect structures or developments from actual or potential landsliding can be very expensive. Recently the control of landslides that threaten important dams and reservoirs in Canada, Peru, and New Zealand has resulted in large expenditures. In Canada mitigation has prevented reactivation of the prehistoric 1.5-km^3 Downie rock slide along the Columbia River north of Revelstoke, British Columbia (Schuster 1979). Beginning in 1977, drainage measures, augmented by instrumentation, were installed to improve the stability of this massive landslide, the toe of which was to be partially inundated by the reservoir of the under-construction Revelstoke Dam. Costs of preventive measures totaled $21 million Canadian (A.S. Imrie, personal communication, 1984, B.C. Hydro, Vancouver, British Columbia, Canada). Although preventive measures are not landslide damages per se, the funds were spent to reduce the threat of much larger damages.

FIGURE 2-16
(below)
Powderhouse slide, February 6, 1913, Gaillard Cut, Panama Canal, showing destruction of steam shovel and construction railroad (MacDonald 1942).
COURTESY OF PANAMA CANAL COMMISSION

FIGURE 2-17 October 1986 reactivation of Cucaracha landslide in Gaillard Cut, Panama Canal. Slide extended nearly across canal, but much of toe had been removed by dredges by time this photograph was taken.
COURTESY OF PANAMA CANAL COMMISSION

An even larger cost was entailed in controlling movement of a 3-million-m^3 creeping mass of rock and colluvium endangering Tablachaca Dam on the Mantaro River in Peru (Figure 2-18). This dam is Peru's largest producer of electric power. Deere and Perez (1985) noted that approximately $40 million ($50 million) was spent by the Peruvian government in landslide stabilization measures consisting of (*a*) a 460 000-m^3 toe buttress founded on densified river sediments; (*b*) 405 prestressed rock anchors; (*c*) 1300 m of drainage tunnels, 190 radial drains, 21 horizontal drains, and 3300 m of surface ditches; (*d*) 68 500 m^3 of rock excavation; (*e*) numerous inclinometers, piezometers, extensometers, and other instrumentation; and (*f*) improvement of the river-channel flow pattern (Morales Arnao et al. 1984).

FIGURE 2-18 *(below)* Creeping rock slide *(arrows)* endangering Tablachaca Dam and Reservoir, Mantaro River, Peru, February 1982, before costly control measures, consisting primarily of reservoir-level earth buttress, surface and subsurface drainage, and rock anchors, were used to reduce threat of catastrophic slope failure to Peru's largest hydropower dam.

The most expensive landslide stabilization program yet undertaken has been the $220 million works that were recently constructed along the shoreline of proposed Lake Dunstan in southern New Zealand (Bell 1992). This hydroelectric storage reservoir is to be impounded behind the completed Clyde Dam in the schist terrain of Central Otago where large ancient landslide complexes, which border about 25 percent of the reservoir shoreline, pose a potential threat to the long-term operation of the power scheme (Bell 1992; Gillon and Hancox 1992).

On March 5, 1987, two earthquakes shook the eastern slopes of the Andes Mountains in eastern Ecuador, triggering landslides and flooding that resulted in destruction or local severing of nearly 70 km of the Trans-Ecuadorian oil pipeline and the main highway from Quito to the eastern rain forests and oil fields (Figure 2-19) (Nieto and Schuster 1988; Schuster 1991). Economic losses were estimated at $1 billion ($1.15 billion), most of which were due to temporary loss of transport capacity for petroleum and petroleum products. The effects of the widespread denudation on the agricultural and hydroelectric development of the area were impossible to evaluate, but undoubtedly were very large. An estimated 1,000 to 2,000 deaths occurred as a direct result of the landslides and related floods.

The Val Pola rock avalanche, one of the most catastrophic landslides in European history, occurred in the central Italian Alps in July 1987. Following a prolonged period of heavy summer precipitation in the Alps, 35 million m^3 of rock avalanched into the Valtellina south of Bormio (Figure 2-20) (Cambiaghi and Schuster 1989; Govi 1989). Although no cost data for this event have been reviewed, the Val Pola landslide killed 27 people, destroyed four villages that had been evacuated in anticipation of the event, completely buried the main north-south highway in this part of the Alps, and dammed the Adda River. Because of the danger of overtopping and failure of the natural dam, some 25,000 people were evacuated from the valley downstream. The lake was lowered by pumps and siphons, and two 3.5-km-long permanent diversion tunnels were constructed through

FIGURE 2-19 Aerial view of destruction of Trans-Ecuadorian oil pipeline and adjacent Trans-Ecuadorian highway by earthquake-triggered debris flow issuing from minor tributary of Coca River, eastern Ecuador, March 1987.

the left bedrock abutment of the natural dam (Cambiaghi and Schuster 1989). The highway was reconstructed above the toe of the landslide. Because of continuing danger at the site after the 1987 failure, the upper part of the Val Pola landslide was heavily instrumented with microseismic networks, inclinometers, extensometers, piezometers, and meteorological equipment at a total cost of $18 million (an indirect cost of the landslide) (Experimental Institute for Models and Structures, written communication, 1988, Bergamo, Italy).

4. LANDSLIDE CASUALTIES

Human casualties due to landslides have been recorded since people began to congregate and build in areas subject to slope failure. The world's most devastating landslide disasters in terms of numbers of casualties have been triggered by earthquakes; the two worst cases occurred in central China. In 1786 the earthquake of Kangding-Louding in Sichuan Province caused a huge landslide that dammed the Dadu River for 10 days (Li 1989). When the landslide dam was overtopped and failed, the resulting flood extended 1400 km downstream and drowned about 100,000 people. In an even greater tragedy, 200,000 people were killed in the 1920 Gansu Province earthquake from a combination of landslides, collapsed cave homes, fallen buildings, and exposure to the harsh winter climate (Close and McCormick 1922). The description by Close and McCormick suggests that as many as 100,000 were killed by the landslides. In an event similar to that in which the Dadu River was dammed, a 1933 earthquake

FIGURE 2-20 *(below)* Val Pola rock avalanche, northern Italy, July 1987, which destroyed major segment of Highway 38 between Bormio and Sondrio and dammed Adda River to form Lake Val Pola. Note emergency spillway under construction across landslide dam *(bottom left)*.

near Deixi in northwestern Sichuan Province caused landslides that killed 6,800 people directly and drowned at least 2,500 more when the resulting landslide dam failed (Li et al. 1986).

In a similar tragedy in southern Italy, the 1786 Calabria earthquake triggered landslides that killed approximately 50,000 people (Cotecchia et al. 1969). Landslides caused by the quake formed about 250 lakes in the area; secondary deaths occurred for several years after the quake from malaria spread by mosquitoes that bred in the new lakes.

In this century the problem of deaths and injuries due to landslides has been exacerbated by the burgeoning population in landslide-prone areas. Varnes (1981) estimated that during the period 1971–1974 nearly 600 people per year were killed worldwide by slope failures. About 90 percent of these deaths occurred within the Circum-Pacific region (i.e., in or on the margins of the Pacific Basin). Probably the best-known recent catastrophic landslides of the Circum-Pacific region are the debris avalanches of 1962 and 1970 on the slopes of Mt. Huascaran in the Cordillera Blanca of Peru. In January 1962 a large debris avalanche that started on the north peak of Mt. Huascaran obliterated mountain villages, killing some 4,000 to 5,000 people (Cluff 1971). Eight years later an even greater number were killed when a magnitude (**M**) 7.75 earthquake off the coast of Peru triggered another disastrous debris avalanche on the slopes of Mt. Huascaran. This landslide descended into the same valley at average speeds of about 320 km/hr but devastated a much larger area than in 1962, burying the towns of Yungay and Ranrahirca and killing more than 18,000 people (Cluff 1971; Plafker et al. 1971).

Another multiple-hazard catastrophe hit South America in 1985 when volcanic mud flows triggered by a minor eruption of Nevado del Ruiz volcano in Colombia destroyed the city of Armero (pre-eruption population: 29,000) (Voight 1990). More than 20,000 were entombed and 5,000 more were injured. The catastrophic loss of life was partially due to failure in emergency response. The disaster occurred in spite of the fact that Colombian and international scientists, alerted by nearly a year of precursory activity by the volcano, had warned that Ruiz might erupt and had prepared a hazard zoning map that accurately predicted the tragic effect of the eruption weeks before it occurred.

Among industrialized nations, Japan has probably suffered the largest continuing loss of life and property from landslides. Although some landslides in Japan are caused by earthquakes, most are a direct result of heavy rains during the typhoon season. When urban areas are in the path of rapid landslides, extensive damage occurs. For example, in July 1938, Kobe, one of Japan's largest cities, was swept by debris flows generated by torrential rainfall, resulting in 505 deaths and destruction of more than 100,000 homes (Nakano et al. 1974; Fukuoka 1982; Ministry of Construction 1983). In 1983 a heavy rainstorm in Nagasaki and northern Kyushu caused 5,000 slides and debris flows that killed 333 people (National Research Center for Disaster Prevention 1983). Table 2-1 summarizes socioeconomic losses due to catastrophic landslides in Japan from 1938 to 1981; note that Japan has been affected almost annually by catastrophic slope failures resulting in large losses of life and property.

Eisbacher and Clague (1984) presented a fascinating account of fatalities, injuries, and property damage due to landslides in the European Alps for the past 2,000 years in the form of 137 case histories derived from historical and technical records. Details on 17 of the most catastrophic landslides since the 13th century are presented in Table 2-2.

The most disastrous landslide in Europe occurred in 1963 at Vaiont Reservoir in northeastern Italy (Table 2-2, Figure 2-21). This 250-million-m^3 reservoir-induced rock slide traveled at high velocity into the reservoir, sending a wave 260 m up the opposite slope and at least 100 m over the crest of the thin-arch Vaiont Dam into the valley below, where it destroyed five villages and took about 2,000 lives (Kiersch 1964). On the basis of Italian reports, Hendron and Patton (1985) estimated the following economic losses from the slide:

1. Loss of the dam and reservoir: $100 million ($425 million),
2. Other property damage: tens of millions of dollars (in 1990 dollars, approaching $100 million), and
3. Civil suits for personal injury and loss of life: $16 million ($68 million).

Thus, the 1990 equivalent economic loss would be about $600 million without taking into account the value of the lives lost.

The republics of the former Soviet Union have also experienced large loss of life due to landslides; most of the deaths occurred in isolated

Table 2-1
Socioeconomic Losses in Major Landslide Disasters, Japan, 1938–1981 [Ministry of Construction (Japan) 1983]

Date	Prefecture	Landslide Area	No. of Residents Dead or Missing	No. of Homes Destroyed or Badly Damaged
July 1938	Hyogo	Mount Rokko (Kobe and vicinity)	505	130,192
July 1945	Hiroshima	Kure and vicinity	1,154	1,954
Sept. 1947	Gumma	Mount Akagi	271	1,538
July 1951	Kyoto	Kameoka	114	15,141
June 1953	Kumamoto	Mount Aso	102	—[a]
July 1953	Wakayama	Arita River	460	4,772
Aug. 1953	Kyoto	Minamiyamashiro	336	5,122
Sept. 1958	Shizuoka	Kanogawa River	1,094	19,754
Aug. 1959	Yamanashi	Kamanashi River	43	277
June 1961	Nagano	Ina Valley Region	130	3,018
Sept. 1966	Yamanashi	Lake Saiko	32	81
July 1967	Hyogo	Mount Rokko	92	746
July 1967	Hiroshima	Kure and vicinity	88	289
July 1972	Kumamoto	Amakusa Island	115	750
Aug. 1972	Niigata	Kurokawa Village	31	1,102
July 1974	Kagawa	Shodo-shima Island	29	1,139
Aug. 1975	Aomori	Mount Iwaki	22	28
Aug. 1975	Kochi	Niyodo River	68	536
Sept. 1976	Kagawa	Shodo-shima Island	119	2,001
May 1978	Niigata	Myoko-Kogen	13	25
Oct. 1978	Hokkaido	Mount Usu	3	144
Aug. 1979	Gifu	Horadani	3	16
Aug. 1981	Nagano	Ubara	10	56

NOTE: Each of these catastrophic mass movements was caused by heavy rainfall, commonly related to typhoons. None was caused by earthquakes or volcanic activity.
[a] No data.

catastrophes. The greatest of these in this century occurred in 1949, when the **M** 7.5 Khait earthquake in Soviet Tadzhikistan triggered a series of debris avalanches and flows that buried 33 villages. Estimates of the number of deaths from these landslides ranged from 12,000 (Jaroff 1977) to 20,000 (Wesson and Wesson 1975). Some large cities of the former USSR, such as Alma-Ata, Dushanbe, Frunze, and Yerevan, are located in valleys that are subject to dangerous debris flows (Gerasimov and Zvonkova 1974). For example, in 1921 a large debris flow passed through Alma-Ata, the capital of the Kazakh Republic, killing 500 people and inflicting considerable damage on the city (Yesenov and Degovets 1982).

Landslide deaths in the United States have been estimated at 25 to 50 per year (Committee on Ground Failure Hazards 1985). About five people per year are killed by landslides in Canada (S. G. Evans, personal communication, 1987, Geological Survey of Canada, Ottawa). Most of

FIGURE 2-21
Vaiont rock slide, northeastern Italy, 1963: 250-million-m^3 rock slide caused Vaiont Reservoir to catastrophically overtop its dam, resulting in extensive property damage and loss of life.

Table 2-2
Major Landslide Disasters in European Alps Since 13th Century (Eisbacher and Clague 1984)

Year	Location	Type of Slope Failure	No. of Deaths
1219	Plaine d'Oisans (Romanche River valley), France	Failure of landslide dam, resulting in downstream flooding	"Thousands"
1248	Mount Granier, France	Rock avalanche	1,500–5,000
1348	Dobratsch Massif, Austria	Earthquake-triggered rock falls and rock avalanches	Heavy losses
1419	Ganderberg-Passeier Wildsee (Passer valley), Italy	Failure of rock-slide dam, resulting in downstream flooding	~400
1486	Zarera (Val Lagune), Switzerland	Rock avalanche	300
1499	Kienholz (Brienzer See), Switzerland	Debris flow	~400
1515	Biasca (Val Blenio), Switzerland	Failure of rock-avalanche dam, resulting in downstream flooding	~600
1569	Hofgastein (Gastein Valley), Austria	Debris flow	147
1569	Schwaz (Inn Valley), Austria	Debris flow	140
1584	Corbeyrier-Yvorne (Tour d'Ai), Switzerland	Debris flow	328
1618	Piuro (Val Bregaglia), Italy	Rock-debris avalanche	~1,200
1669	Salzburg, Austria	Rock topple–rock fall	250
1806	Goldau (Rossberg Massif), Switzerland	Rock avalanche	457
1814	Antelao Massif (Boite Valley), Italy	Rock avalanche	300
1881	Elm (Sernf Valley), Switzerland	Rock avalanche	115
1892	St. Gervais (Arve Valley), France	Ice-debris flow	177
1963	Vaiont Reservoir (Piave Valley), Italy	Rock slide caused flooding along shore of reservoir and downstream	~1,900

these are killed by relatively small events, most commonly by rock falls. Although there have been some very large and catastrophic landslides in North America, most have occurred in mountainous, relatively unpopulated areas; thus, these failures commonly have not resulted in major losses of life. However, there have been several notable exceptions. In 1903 a great rock slide killed about 70 people in the coal mining town of Frank, Alberta, Canada (McConnell and Brock 1904). A more recent Canadian catastrophe was the 1971 flow failure in sensitive clay that demolished part of the town of Saint-Jean-Vianney, Quebec, destroying 40 homes and killing 31 people (Tavenas et al. 1971). By far the most disastrous landslide (in terms of lives lost) to occur within the territory of the United States occurred on the island of Puerto Rico in October 1985 when heavy rainfall from Tropical Storm Isabel caused a major rock slide (Figure 2-22) that obliterated much of the Mameyes district of the city of Ponce. The slide killed at least 129 people and destroyed about 120 houses (Jibson 1992). The death toll at Mameyes was the greatest from a single slide in North American history.

Interestingly, the world's two largest landslides in modern history have resulted in relatively few casualties. The 1911 Usoy landslide in Soviet Tadzhikistan (then Russia), with an estimated volume of 2.5 km^3, was a truly catastrophic event. However, in spite of the great volume and apparently high velocity of this earthquake-triggered landslide, casualties were low because the area was sparsely populated. Most of the deaths occurred in the village of Usoy, whose 54 inhabitants were buried (Bolt et al. 1975, 178–179). This landslide also formed the world's highest historic landslide dam, a 570-m-high blockage of the Murgob River that still impounds 60-km-long Lake Sarez. The natural dam is being considered as the site of a hydroelectric power project. The 2.8-km^3 rock slide–debris avalanche (Figure 2-10) that accompanied the 1980 eruption of Mount St. Helens in Washington State is the world's largest historic landslide. However, even though this huge mass moved down valley at high velocity, it killed only 5 to 10 people (Schuster 1983). The low casualty rate was a direct result of the evacuation of residents and visitors in anticipation of a possible eruption of the volcano.

The economic value of loss of life due to landslides has not commonly been included in calculating the costs of landslides because it is difficult to place a specific value on a human life. However, in cost-benefit studies, federal agencies in the United States recently have assigned human-life

values with a median of roughly $2 million each (Scanlan 1990). If these values are realistic, the economic losses due to the 25 to 50 annual landslide deaths in the United States are on the order of $50 million per year to $100 million per year.

5. POSITIVE EFFECTS OF LANDSLIDES

Landslides constitute a major element in mass wasting of the continents. Thus, in terms of geologic time, they help to provide stable land that is suitable for agriculture and habitation. In the shorter term, it is difficult to conceive of benefits that might accrue as a result of natural landslide activity. However, in a few cases landslides were purposely triggered to obtain socioeconomic benefits. An example is a 100-m-high sediment-retention dam on the Malaya Alma-Atinka River upstream from Alma-Ata in the Kazakh Republic of the former Soviet Union (Yesenov and Degovets 1982). This dam, which was constructed in 1966–1967, protects Alma-Ata from the debris flows mentioned earlier. It was formed from landslides that were triggered by setting off large explosive charges in the valley walls. The resulting landslide dam was then shaped into a traditional check dam by means of earth-moving equipment. Engineers and scientists from the former Soviet Union plan to use the experience gained from this artificially made landslide dam to construct a much larger hydropower dam on the Naryn River in the Republic of Kyrgyzstan (Adushkin 1993). The three artificially made landslides that will form the 270-m-high landslide dam, which will be the main component of the Kambarata hydropower project, will be triggered by 250 tons of chemical explosives. Power will be generated by means of flow through a penstock that will bypass the landslide dam through its bedrock right abutment.

6. CONCLUSIONS

In many countries, socioeconomic losses due to landslides are great and apparently are growing as human development expands into unstable hillslope areas under the pressures of increasing populations. A significant proportion of world landslide losses affect transportation facilities: highways, railways, canals, and pipelines. The nation most severely affected by landslides is Japan, which suffers estimated total (direct plus indirect) landslide losses of $4 billion annually. In the United States, Italy, and India, total annual economic losses due to landslides have been estimated to range from $1 billion to $2 billion. Many other countries have lesser, but major, annual landslide losses.

FIGURE 2-22 October 1985, Mameyes, Puerto Rico, rock slide: triggered by rainfall, 300 000-m^3 landslide killed at least 129 people.
R. W. JIBSON, U.S. GEOLOGICAL SURVEY

On the basis of worldwide data for 1971–1974, nearly 600 people a year are killed by landslides. However, tens of thousands have been killed in the 20th century in each of a few truly disastrous landslides, a fact that raises the average annual number of worldwide landslide deaths for this century to well above the 600 recorded for 1971–1974. Landslide deaths in the United States are estimated at 25 to 50 a year.

REFERENCES

Adushkin, V.V., L.M. Pernik, and Y.N. Zykov. 1993. Modeling of Explosion-Triggered Rock Slides for Construction of the Kambarata I Hydroelectric Power Dam, Republic of Kyrgyzstan. *Landslide News* (Japan Landslide Society), No. 7, pp. 7–9.

Anderson, L.R., J.R. Keaton, T. Saarinen, and W.G. Wells II. 1984. *The Utah Landslides, Debris Flows, and Floods of May–June 1983*. National Research Council, Washington, D.C., 96 pp.

Association of Engineering Geologists. 1984. Southern California—Section News. *Newsletter*, Vol. 27, No. 3, p. 34.

Ayala, F.J., and M. Ferrer. 1989. Extent and Economic Significance of Landslides in Spain. In *Landslides: Extent and Economic Significance* (E.E. Brabb and B.L. Harrod, eds.), Proc., 28th International Geological Congress: Symposium on Landslides, Washington, D.C., July 17, 1989, A.A. Balkema, Rotterdam, Netherlands, pp. 169–178.

Bell, D.H. 1992. Preface. In *Landslides: Proc., Sixth International Symposium on Landslides* (D.H. Bell, ed.)., Christchurch, New Zealand, Feb. 10–14, A.A. Balkema, Rotterdam, Netherlands, Vol. 1, pp. vii–viii.

Berman, G. 1991. Landslides on the Panama Canal. *Landslide News* (Japan Landslide Society), No. 5, pp. 10–14.

Bolt, B.A., W.L. Horn, G.A. Macdonald, and R.F. Scott. 1975. *Geological Hazards*. Springer-Verlag, New York, 328 pp.

Brabb, E.E. 1984. *Minimum Landslide Damage in the United States*. U.S. Geological Survey Open-File Report 84-486, 4 pp.

Brabb, E.E. 1989. Landslides: Extent and Economic Significance in the United States. In *Landslides: Extent and Economic Significance* (E.E. Brabb and B.L. Harrod, eds.), Proc., 28th International Geological Congress: Symposium on Landslides, Washington, D.C., July 17, A.A. Balkema, Rotterdam, Netherlands, pp. 325–350.

Brand, E.W. 1989. Occurrence and Significance of Landslides in Southeast Asia. In *Landslides: Extent and Economic Significance* (E.E. Brabb and B.L. Harrod, eds.), Proc., 28th International Geological Congress: Symposium on Landslides, Washington, D.C., July 17, 1989, A.A. Balkema, Rotterdam, Netherlands, pp. 303–324.

Cambiaghi, A., and R.L. Schuster. 1989. Landslide Damming and Environmental Protection—A Case Study from Northern Italy. In *Proc., Second International Symposium on Environmental Geotechnology*, Shanghai, May 15–18, 1989, Envo Publishing Company, Inc., Bethlehem, Pa., Vol. 1, pp. 469–480.

Cato, I. 1982. The 1977 Landslide at Tuve and the Complex Origin of Clays in South-western Sweden. In *Landslides and Mudflows: Reports of the Alma-Ata International Seminar, October 1981* (A.I. Sheko, ed.), Centre of International Projects, GKNT, Moscow, pp. 279–289.

Charma, C.K. 1974. *Landslides and Soil Erosion in Nepal*. Sangeeta Publishers, Kathmandu, Nepal, 93 pp.

Chassie, R.G., and R.D. Goughnour. 1976a. National Highway Landslide Experience. *Highway Focus*, Vol. 8, No. 1, pp. 1–9.

Chassie, R.G., and R.D. Goughnour. 1976b. States Intensifying Efforts to Reduce Highway Landslides. *Civil Engineering*, Vol. 46, No. 4, pp. 65–66.

Chopra, B.R. 1977. Landslides and Other Mass Movements Along Roads in Sikkim and North Bengal. *Bulletin of the International Association of Engineering Geology*, No. 16, pp. 162–166.

Close, U., and E. McCormick. 1922. Where the Mountains Walked. *National Geographic Magazine*, Vol. 41, No. 5, pp. 445–464.

Cluff, L.S. 1971. Peru Earthquake of May 31, 1970; Engineering Geology Observations. *Seismological Society of America Bulletin*, Vol. 61, No. 3, pp. 511–521.

Committee on Ground Failure Hazards. 1985. *Reducing Losses from Landslides in the United States*. Commission on Engineering and Technical Systems, National Research Council, Washington, D.C., 41 pp.

Cotecchia, V., G. Travaglini, and G. Melidoro. 1969. I Movimenti Franosi e gli Sconvolgimenti della Rete Idrografica Prodotti in Calabria dal Terremoto del 1783. *Geologia Applicata e Idrogeologia* (Italy), Vol. 4, pp. 1–24.

Coulter, H.W., and R.R. Migliaccio. 1966. *Effects of the Earthquake of March 17, 1964, at Valdez, Alaska*. U.S. Geological Survey Professional Paper 542-C, pp. C1–C36.

Council of Economic Advisers. 1991. *Economic Report of the President, 1991*. Washington, D.C., 411 pp.

Creasey, C.L. 1988. Landslide Damage: A Costly Outcome of the Storm. In *Landslides, Floods, and Marine Effects of the Storm of January 3–5, 1982, in the San Francisco Bay Region, California* (S.D. Ellen and G.F. Wieczorek, eds.), U.S. Geological Survey Professional Paper 1434, pp. 195–203.

Deere, D.U., and J.Y. Perez. 1985. Remedial Measures for Large Slide Movements. In *Proceedings of P.R.C.-U.S.-Japan Trilateral Symposium/Workshop on Engineering for Multiple Natural Hazard Mitigation*, Beijing, People's Republic of China, Jan. 7–12, pp. L-7-1 to L-7-15.

Dracup, J.A., E.D.H. Cheng, J.M. Nigg, and T.A. Schroeder. 1991. *The New Year's Eve Flood on Oahu, Hawaii—December 31, 1987–January 1, 1988*. Natural Disaster Studies, Vol. 1. Committee on Natural Disasters, National Research Council, Washington, D.C., 72 pp.

Eisbacher, G.H., and J.J. Clague. 1984. *Destructive Mass Movements in High Mountains: Hazard and Management*. Geological Survey Canada Paper 84-16, Ottawa, 230 pp.

Facts on File Yearbook. 1990. Tropical Forest Loss Reported. Facts on File Publications, New York, pp. 528–529.

Fleming, R.W. 1981. Stop 1: Landslide Damage in Greater Cincinnati. In *Engineering Geology of the Cincinnati Area* (R.W. Fleming, A.M. Johnson, and J.E. Hough, eds.), Annual Meeting, Geo-

logical Society of America, Cincinnati, Field Trip No. 18, pp. 543–570.

Fleming, R.W., and F.A. Taylor. 1980. *Estimating the Costs of Landslide Damage in the United States*. U.S. Geological Survey Circular 832, 21 pp.

Fukuoka, M. 1982. Some Case Studies on Landslides in Japan. In *Landslides and Mudflows—Reports of the Alma-Ata International Seminar, October 1981* (A.I. Sheko, ed.), Centre of International Projects, GKNT, Moscow, pp. 333–352.

Gerasimov, I.P., and T.B. Zvonkova. 1974. Natural Hazards in the Territory of the USSR: Study, Control, and Warning. In *Natural Hazards—Local, National, Global* (G.F. White, ed.), Oxford University Press, New York, pp. 243–251.

Gillon, M.D., and G.T. Hancox. 1992. Cromwell Gorge Landslides—A General Overview. In *Landslides: Proc., Sixth International Symposium on Landslides* (D.H. Bell, ed.), Christchurch, New Zealand, Feb. 10–14, A.A. Balkema, Rotterdam, Netherlands, Vol. 1, pp. 83–102.

Govi, M. 1989. The 1987 Landslide on Mount Zandila in the Valtellina, Northern Italy. *Landslide News* (Japan Landslide Society), No. 3, pp. 1–3.

Gregersen, O., and F. Sandersen. 1989. Landslides: Extent and Economic Significance in Norway. In *Landslides: Extent and Economic Significance* (E.E. Brabb and B.L. Harrod, eds.), Proc., 28th International Geological Congress: Symposium on Landslides, Washington, D.C., July 17, A.A. Balkema, Rotterdam, Netherlands, pp. 133–139.

Hansen, W.R. 1965. *Effects of the Earthquake of March 27, 1964 at Anchorage, Alaska*. U.S. Geological Survey Professional Paper 542-A, pp. A1–A68.

Hawley, J.G. 1984. Slope Instability in New Zealand. In *Natural Hazards in New Zealand* (I. Spedon and M.J. Crozier, eds.), National Commission for UNESCO, Wellington, New Zealand, pp. 88–13.

Hendron, A.J., Jr., and F.D. Patton. 1985. *The Vaiont Slide: A Geotechnical Analysis Based on New Geologic Observations of the Failure Surface*. Waterways Experiment Station Technical Report, U.S. Army Corps of Engineers, Vicksburg, Miss., Vol. 1, 104 pp.

Honolulu Star-Bulletin. 1989. Kuliouou Residents Say a Fond, Sad Aloha. Aug. 8, p. A-3.

Jaroff, L. 1977. Forecasting the Earth's Convulsions. In *Nature/Science Annual*, 1977 Edition. Time-Life Books, New York, pp. 21–33.

Jibson, R.W. 1992. The Mameyes, Puerto Rico, Landslide Disaster of October 7, 1985. In *Landslides/Landslide Mitigation* (J.A. Johnson and J.E. Slosson, eds.), Geological Society of America, Reviews in Engineering Geology, Vol. 9, Chap. 5, pp. 37–54.

Jones, F.O., D.R. Embody, and W.L. Peterson. 1961. *Landslides along the Columbia River Valley, Northeastern Washington*. U.S. Geological Survey Professional Paper 367, 98 pp.

Kaliser, B.N. 1983. Geologic Hazards of 1983. *Survey Notes, Utah Geological and Mineral Survey*, Salt Lake City, Vol. 17, No. 2, pp. 3–8, 14.

Khegai, A.Y., and N.V. Popov. 1989. The Extent and Economic Significance of the Debris Flow and Landslide Problem in Kazakhstan, in the Soviet Union. In *Landslides: Extent and Economic Significance* (E.E. Brabb and B.L. Harrod, eds.), Proc., 28th International Geological Conference: Symposium on Landslides, Washington, D.C., July 17, A.A. Balkema, Rotterdam, Netherlands, pp. 221–225.

Kiersch, G.A. 1964. Vaiont Reservoir Disaster. *Civil Engineering*, Vol. 34, No. 3, pp. 32–39.

Kotarba, A. 1989. Landslides: Extent and Economic Significance in Central Europe. In *Landslides: Extent and Economic Significance* (E.E. Brabb and B.L. Harrod, eds.,), Proc., 28th International Geological Congress: Symposium on Landslides, Washington, D.C., July 17, A.A. Balkema, Rotterdam, Netherlands, pp. 191–202.

Krohn, J.P., and J.E. Slosson. 1976. Landslide Potential in the United States. *California Geology*, Vol. 29, No. 10, pp. 224–231.

Legget, R.F. 1973. *Cities and Geology*. McGraw-Hill, New York, 624 pp.

Li Tianchi. 1989. Landslides: Extent and Economic Significance in China. In *Landslides: Extent and Economic Significance* (E.E. Brabb and B.L. Harrod, eds.), Proc., 28th International Geological Congress: Symposium on Landslides, Washington, D.C., July 17, A.A. Balkema, Rotterdam, Netherlands, pp. 271–287.

Li Tianchi, R.L. Schuster, and Wu Jishan. 1986. Landslide Dams in South-central China. In *Landslide Dams—Processes, Risk, and Mitigation* (R.L. Schuster, ed.), American Society of Civil Engineers Geotechnical Special Publication No. 3, pp. 146–162.

Los Angeles Times. 1984. 13 Malibu Families Flee Landslide—Mesa Homes Inch Toward Cliff Overlooking Coast Highway, Los Angeles, California. March 3, pp. 1 and 6.

Lutton, R.J., D.C. Banks, and W.E. Strohm, Jr. 1979. Slides in Gaillard Cut, Panama Canal Zone. In *Rockslides and Avalanches, 2: Engineering Sites* (B. Voight, ed.), Elsevier, New York, pp. 151-224.

MacDonald, D.F. 1942. *Panama Canal Slides—The Third Locks Project*. Department of Operation and Maintenance, Special Engineering Division, The Panama Canal Company, Balboa Heights, Panama Canal Zone, 73 pp.

Malone, F. 1983. D and RGW Digs Out—Fast. *Railway Age*, Sept., pp. 42–43.

Marinatos, S.N. 1960. Helice: A Submerged Town of Classical Greece. *Archaeology*, Vol. 13, No. 3, pp. 186–193.

Mathur, H.N. 1982. Influence of Human Activities on Landslides, Mudflows and Slope Movements in India and Efforts at Reducing Their Negative Impact. In *Landslides and Mudflows—Reports of the Alma-Ata International Seminar, October 1981* (A.I. Sheko, ed.), Centre of International Projects, GKNT, Moscow, pp. 20–44.

McConnell, R.G., and R.W. Brock. 1904. The Great Landslide at Frank, Alberta. In *Annual Report of the Canada Department of the Interior for the Year 1902-03*, Session Paper 25, Canada Department of the Interior, Ottawa, pp.1–17.

Merriam, R. 1960. Portuguese Bend Landslide, Palos Verdes, California. *Journal of Geology*, Vol. 68, No. 2, pp. 140–153.

Ministry of Construction (Japan). 1983. *Reference Manual on Erosion Control Works* (in Japanese). Erosion Control Department, Japan, 386 pp.

Morales Arnao, B., V.K. Garga, R.S. Wright, and J.Y. Perez. 1984. The Tablachaca Slide No.5, Peru, and Its Stabilization. In *Proc., Fourth International Symposium on Landslides*, Toronto, Vol. 1, pp. 597–604.

Moriyama, Y., and S. Horiuchi. 1993. The Budget for Fiscal 1993 (in Japanese). *Sabo and Flood Control*, Japan Sabo Association, Vol. 25, No. 6, pp. 60–64.

Nakano, T., H. Kadomura, T. Mizutani, M. Okuda, and T. Sekiguchi. 1974. Natural Hazards—Report from Japan. In *Natural Hazards—Local, National, Global* (G.F. White, ed.), Oxford University Press, New York, Chap. 28, pp. 231–243.

National Research Center for Disaster Prevention (Japan). 1983. *Outline of Recent Activities of the National Research Center for Disaster Prevention*. Science and Technology Agency, Japan, 131 pp.

Nieto, A.S., and R.L. Schuster. 1988. Mass Wasting and Flooding Induced by the 5 March 1987 Ecuador Earthquakes. *Landslide News* (Japan Landslide Society), No. 2, pp. 5–8.

Nishimoto, H. 1993. The Supplementary Budget for Fiscal 1992. *Sabo and Flood Control*, Japan Sabo Association, Vol. 25, No. 6, pp. 68–69.

Oyagi, N. 1989. Geological and Economic Extent of Landslides in Japan and Korea. In *Landslides: Extent and Economic Significance* (E.E. Brabb and B.L. Harrod, eds.), Proc., 28th International Geological Congress: Symposium on Landslides, Washington, D.C., July 17, A.A. Balkema, Rotterdam, Netherlands, pp. 289–302.

Plafker, G., G.E. Ericksen, and J. Fernandez Concha. 1971. Geological Aspects of the May 31, 1970, Peru Earthquake. *Seismological Society of America Bulletin*, Vol. 61, No. 3, pp. 543–578.

Radbruch-Hall, D.H., R.B. Colton, W.E. Davies, I. Lucchita, B.A. Skip, and D.J. Varnes. 1982. *Landslide Overview Map of the Conterminous United States*. U.S. Geological Survey Professional Paper 1183, 25 pp.

Sager, J.W., and C.M. Budai. 1989. Geology and Construction of the Spirit Lake Outlet Tunnel, Mount St. Helens, Washington. In *Engineering Geology in Washington*, Bulletin 78, Washington Division of Geology and Earth Resources, Olympia, Vol. 2, pp. 1229–1234.

San Francisco Chronicle. 1983. Highway 50 Reopens and Tahoe Rejoices. June 24, p. 2.

Scanlan, C. 1990. Placing a Value on Life a Vital Part of Federal Cost-Benefit Trade-Offs. *Denver Post*, July 14.

Schuster, R.L. 1978. Introduction. In *Special Report 176: Landslides—Analysis and Control* (R.L. Schuster and R.J. Krizek, eds.), TRB, National Research Council, Washington, D.C., Chap. 1, pp. 1–10.

Schuster, R.L. 1979. Reservoir-Induced Landslides. *Bulletin of the International Association of Engineering Geology*, No. 20, pp. 8–15.

Schuster, R.L. 1983. Engineering Aspects of the 1980 Mount St. Helens Eruptions. *Bulletin of the Association of Engineering Geologists*, Vol. 20, No. 2, pp. 125–143.

Schuster, R.L. 1991. Introduction. In *The March 5, 1987, Ecuador Earthquakes—Mass Wasting and Socioeconomic Effects*, Natural Disaster Studies, Vol. 5, Committee on Natural Disasters, National Research Council, Washington, D.C., pp. 11–22.

Schuster, R.L., and L.D. Alfaro. 1992. Landslide Hazards in the Gaillard Cut, Panama Canal Zone. *Abstracts with Programs*, 1992 Annual Meeting of the Geological Society of America, Vol. 24, No. 7, p. A166.

Schuster, R.L., and R.W. Fleming. 1986. Economic Losses and Fatalities due to Landslides. *Bulletin of the Association of Engineering Geologists*, Vol. 23, No. 1, pp. 11–28.

Schuster, R.L., and R.W. Fleming. 1988. Socioeconomic Significance of Landslides and Mudflows. In *Landslides and Mudflows* (E.A. Kozlovskii, ed.), UNESCO/UNEP, Moscow, pp. 131–141.

Seed, H.B. 1968. Landslides during Earthquakes due to Soil Liquefaction. *Journal of the Soil Mechanics and Foundations Division*, ASCE, Vol. 94, No. SM5, pp. 1055–1122.

Shearer, C.F., F.A. Taylor, and R.W. Fleming. 1983. *Distribution and Costs of Landslides in San Diego County, California, during the Rainfall Years of 1978–79 and 1979–80*. U.S. Geological Survey Open-File Report 83-582, 15 pp.

Slosson, J.E. 1987. Landslides and Other Ground Failure Hazards: Where Have We Failed? *Abstracts with Programs*, 83rd Annual Meeting, Cordilleran Section, Geological Society of America, Vol. 19, No. 6, p. 452.

Slosson, J.E., and J.P. Krohn. 1982. Southern California Landslides of 1978 and 1980. In *Proc., Floods and Debris Flows in Southern California and Arizona, 1978 and 1980*, Sept. 17–18, 1980, National Research Council; Environmental Quality Laboratory, California Institute of Technology, Pasadena, pp. 291–319.

Smith, R. 1958. Economic and Legal Aspects. In *Special Report 29: Landslides and Engineering Practice* (E.B. Eckel, ed.), HRB (now TRB), National Research Council, Washington, D.C., National Research Council Publication 544, pp. 6–19.

Smith, T.C. 1982. Lawsuits and Claims against Cities and Counties Mount after January 1982 Storm. *California Geology*, Vol. 35, No. 7, pp. 163–164.

Soil Conservation Service. 1986. *Tomiki Creek Unit, Redwood Empire Target Area, Mendocino County, California*. U.S. Department of Agriculture, Davis, Calif., 264 pp.

Tan, S.S. 1980. Slope Failures in Orange County due to 1978 Rains. *California Geology*, Vol. 33, No. 9, pp. 202–205.

Tavenas, F., J.Y. Chagnon, and P. LaRochelle. 1971. The Saint-Jean-Vianey Landslide—Observations and Eyewitness Accounts. *Canadian Geotechnical Journal*, Vol. 8, No. 3, pp. 202–205.

Taylor, F.A., and E.E. Brabb. 1972. *Maps Showing Distribution of and Cost by Counties of Structurally Damaging Landslides in the San Francisco Bay Region, California, Winter 1968–69*. U.S. Geological Survey Miscellaneous Field Studies Map MF-327.

University of Utah. 1984. *Flooding and Landslides in Utah—An Economic Impact Analysis*. University of Utah Bureau of Economic and Business Research, Utah Department of Community and Economic Development, and Utah Office of Planning and Budget, Salt Lake City, 123 pp.

Varnes, D.J. 1981. Slope-Stability Problems of the Circum-Pacific Region as Related to Mineral and Energy Resources. In *Energy Resources of the Pacific Region* (M.T. Halbouty, ed.), American Association of Petroleum Geologists Studies in Geology, No. 12, pp. 489–505.

Voight, B. 1990. The 1985 Nevado del Ruiz Volcano Catastrophe: Anatomy and Retrospection. *Journal of Volcanology and Geothermal Research*, Vol. 44, pp. 349–386.

Voight, B., R.J. Janda, H. Glicken, and P.M. Douglass. 1983. Nature and Mechanisms of the Mount St. Helens Rock-Slide Avalanche of 18 May 1980. *Geotechnique*, Vol. 33, No. 3, pp. 243–273.

Vonder Linden, K. 1989. The Portuguese Bend Landslide. *Engineering Geology*, Vol. 27, pp. 301–373.

Walkinshaw, J. 1992. Landslide Correction Costs on U.S. State Highway Systems. In *Transportation Research Record 1343*, TRB, National Research Council, Washington, D.C., pp. 36–41.

Wesson, C.V.K., and R.L. Wesson. 1975. Odyssey to Tadzhik—An American Family Joins a Soviet Seismological Expedition. *U.S. Geological Survey Earthquake Information Bulletin*, Vol. 7, No. 1, pp. 8–16.

Wiggins, J.H., J.E. Slosson, and J.R. Krohn. 1978. *National Hazards—Earthquake, Landslide, Expansive Soil Loss Models*. Technical Report, J.H. Wiggins Co., Redondo Beach, Calif., 162 pp.

Xue-Cai, F., and G. An-ning. 1986. Principal Characteristics of Earthquake Landslides in China. *Geologia Applicata e Idreogeologia* (Italy), Vol. 21, No. 2, pp. 27–45.

Yesenov, Y.E., and A.S. Degovets. 1982. Protection of the City of Alma-Ata from Mud-Rock Flows. In *Landslides and Mudflows—Reports of the Alma-Ata International Seminar, October 1981* (A.I. Sheko, ed.), Centre of International Projects, GKNT, Moscow, pp. 454–465.

Youd, T.L. 1978. Major Cause of Earthquake Damage Is Ground Failure. *Civil Engineering*, ASCE, Vol. 48, No. 4, pp. 47–51.

Youd, T.L., and S.N. Hoose. 1978. *Historic Ground Failures in Northern California Triggered by Earthquakes*. U.S. Geological Survey Professional Paper 993, 177 pp.