by Earl E. Brabb

The World Landslide Problem

Thousands of people may be killed by landslides each year and property damage may be in the tens of billions of dollars, but the techniques for recognizing and coping with landslides are well developed. Landslides are generally more manageable and predictable than earthquakes, volcanic eruptions, and some storms, but only a few countries have taken advantage of this knowledge to reduce landslide hazards.

Introduction

Landslides are the consequence of diverse and complex processes that probably affect every country that has topographic relief. Many move so slowly that the effects are barely discernible, others move hundreds of kilometers an hour, obliterating everything in their path. Landslides are most commonly triggered by precipitation, but earthquake- and volcano-triggered landslides have killed more people than all other types of landslides combined. The masking of landslide damage by earthquakes, volcanoes, and floods, and the lack of landslide damage statistics in most countries have led to widespread ignorance about the social, economic, and political consequences of landslide processes, and a paucity of programs for reducing the hazard. This lack is unfortunate because landslides are generally more predictable and manageable than earthquakes, volcanic eruptions, and many types of storms.

Classification

Many classification schemes have been devised to explain landslide processes, but the one by Varnes (1978) shown in fig. 1 is used by most researchers. The basic divisions in the Varnes classification are the type of movement—fall, topple, slide, spread, and flow—and the kind of material involved. Note that Varnes prefers the term "slope movements." I will use the more familiar "landslides" in this paper, even though many processes loosely termed "landslides" involve little or no true sliding.

TYPE OF MOVEMENT			TYPE OF MATERIAL		
			BEDROCK	ENGINEERING SOILS	
				Predominantly coarse	Predominantly fine
FALLS			Rock fall	Debris fall	Earth fall
TOPPLES			Rock topple	Debris topple	Earth topple
SLIDES	ROTATIONAL	FEW UNITS	Rock slump	Debris slump	Earth slump
	TRANSLATIONAL		Rock block slide	Debris block slide	Earth block slide
		MANY UNITS	Rock slide	Debris slide	Earth slide
LATERAL SPREADS			Rock spread	Debris spread	Earth spread
FLOWS			Rock flow (deep creep)	Debris flow	Earth flow
				(soil creep)	
COMPLEX			Combination of two or more principal types of movement		

Figure 1.—Abbreviated classification of slope movements (from Varnes, 1978).

Geographic Extent

Landslides are prevalent in mountainous areas of North, Central, and South America, Europe, Africa, and Asia. A book edited by Brabb and Harrod (1989) has reports on landslides in more than 100 countries and areas, including Antarctica and subsea and island areas in the Pacific Ocean basin. Brabb (1989) estimates that the United States alone may have as many as 20 million landslide deposits. Moore and others (1989) indicate that some of the subsea landslides on the Hawaiian Islands cover an area more than five times the land area of the Hawaiian Islands, and that some are more than 200 km long and about 5,000 km^3 in volume, ranking them among the largest landslides on earth. Many of the subsea landslides and some on land occur on very low slopes, providing evidence that landslides can occur even in areas without considerable topographic relief.

Impact

Thousands of people may be killed by landslides each year, and property damage may be in the tens of billions of dollars, judging from fragmentary information available for a few countries (Tables 1 and 2 and Blackwell, 1989). The paucity of information for Africa is probably related partly to large areas of desert and semiarid terrain where landslides are less abundant than on other continents, lack of infrastructure in areas of high relief and heavy rainfall, and scarcity of systems for reporting landslide damage and fatalities that do occur.

Recognition

Recognition and identification of the types of landslides goes back at least to 186 B.C. in China (Li, 1989), but systematic identification and mapping of all landslide types in specific areas have developed mainly during the past few decades. For example, geologic maps published around the turn of the century did not show a single landslide in the San Francisco Bay region of California. By 1970, approximately 1,200 landslides had been mapped in the region. By 1980, after special landslide mapping programs had been carried out by Federal, State, and local governments, 70,000 landslides had been identified. In 1982, high-intensity rainfall triggered 18,000 new landslides, most of them in areas not previously mapped as underlain by landslide deposits (Ellen and others, 1988). In most other areas of the United States and in most other countries, the status of regional knowledge about landslide distribution is comparable to that in the San Francisco Bay region prior to 1970; landslide inventory maps at a scale of 1:100,000 or larger probably cover less than 1 percent of the land and sea areas of the world.

Table 1.—Economic and social impact of landsliding in the few countries that have this information. From reports in the book edited by Brabb and Harrod (1989)

Canada: Losses may be hundreds of millions of dollars annually. 365 deaths by landslide processes in the Canadian Cordillera since 1855. 100 people killed by rockslides in Quebec between 1836 and 1889. At least 100 killed in sensitive clay slides.
United States: Average annual cost of landsliding estimated to be $1.5 billion, with at least 25 fatalities.
Carribean: At least 214 people killed by landslides since 1938. Annual cost of repairing landslide damage to roads is $15 million.
Costa Rica: $12 million in damages and at least 3 people killed by landsliding and flooding in 1987.
Panama: Approximately 700 km^2 denuded by liquefaction and landsliding triggered by earthquakes in 1976.
Andes: Catastrophic landslides at 5- to 10-year intervals may cause property damage in the hundreds of millions of dollars and kill hundreds or even thousands of people. Nevados Huascaran avalanche of 1970 killed about 20,000 people. Since 1940, landslide damage has been at least $1 billion, and more than 25,000 people have been killed.
Ecuador: Landslide fatalities have increased from 10 people in the 1950's to at least 1,290 people in the 1980's. Landslides in 1987 severed 33 km of oil pipeline, reducing government income by 35 percent.
Norway: At least 750 people killed by landslides since 1345.
Denmark: The cost of repairing and preventing landslides is estimated to be $1–3 million annually.
Poland: At least 1,000 landslides have damaged roads.
Czechoslovakia: 548 villages and towns are at risk.
Bulgaria: Nine villages have been abandoned and 12 others are in danger from landsliding.
Hungary: The largest iron and steel center along the Danube has been adversely affected by a landslide.
Spain: Landslide damages estimated at $220 million per year. Total loss for next 30 years could exceed $6 billion. At least 117 people have been killed by landslides.
Portugal: At least 31 people killed by landsliding.
Soviet Union: Landsliding a pervasive and recurrent problem, causing at least $500 million damage in Kazakhstan alone.
Ghana: Landslide damage to farms, villages, and roads is one-half to one million dollars annually.
Nigeria: Millions of dollars annually in landslide damage to farmlands, villages, and roads.
Southern Africa: Cost of repairing landslide damage to roads and railroads in 1987 was $5–10 million; cost to repair houses was about $2.5 million. Total cost of 1987 landslide damage was probably about $20 million. Average annual cost of landsliding is probably on the order of $10 million.
China: Annual losses due to landslides exceed $0.5 billion. Number of people killed by landslides annually in recent years exceeds 100. In 1786, more than 100,000 people were killed in a single landslide when a landslide dam failed and the water impounded by the dam rushed downstream and overran villages. In 1920, landslides in loess triggered by an earthquake killed another 100,000 people. Since 1310, at least 255,000 people have been killed by landslides in China. Roads, railroads, coal mines, electric plants, steel mills, villages, commercial areas, and navigation on the Changjiang (Yangtze) River have all been adversely affected by landslides.
Australia and New Zealand: Annual losses are in the tens of millions of dollars.
Papua New Guinea: Road closures and damage to villages by landslides are common. A landslide in 1988 killed at least 70 people.
Indonesia: As many as 2,000 people killed each year. 5,110 people were killed by a volcanic mudflow, in 1919.
Malaysia: 246 deaths by flow-slides in tin mine excavations between 1960 and 1980. Many people also killed by rock falls.
Hong Kong: More than 650 mm of rain fell from 16 to 18 June, 1972, causing many landslides and killing 250 people. Hundreds of landslides also occurred on 25 August 1976, killing 57 people. About 1,500 landslides occurred in 1982, killing 48 people.
Sri Lanka: Landslides have killed at least 149 people and have deforested large areas.
Thailand: Debris flows killed as many as 700 people in 1988.
Philippines: Several hundred people killed by landslides in gold mining areas.
Japan: Annual landslide losses may be as much as $4 billion. At least 2,500 people killed from 1967 and 1986. (Figures in book corrected by N. Oyagi, written comm., 1990).

Techniques for recognizing and mapping landslides are numerous and complex; articles by Rib and Liang (1978) and Hansen (1984) provide an overview of the topic and many practical suggestions. Aerial photographs are the principal tool used for mapping the location, type, and cause of movement. Where landslide deposits are concealed by trees or where they have been extensively modified by erosion (fig. 2), they are likely to be overlooked on aerial photographs. Consequent underreporting of the extent of landslides is common even where detailed field examinations have been made.

Research Needed

A balanced program to recognize and mitigate landslides should involve investigation of landslide processes, development of methods to delineate the hazard, and schemes to reduce the losses (fig. 3). All levels of government, academia, and the private sector should be involved. Research needs are greatest for landslide prediction and the establishment of recurrence intervals so that the risk of landslide failure can be determined. Other research needs are mentioned by the U.S. Committee on Ground Failure Hazards (1985), the U.S. Geological Survey (1982), and Crozier (1986).

Susceptibility

Landslide susceptibility maps delineate areas with different potentials for future landslide movement. The maps can be simple extrapolations of landslide-prone geologic units derived from geologic maps (Pomeroy, 1979), or they can be complex, computer-derived mathematical models involving nearly 100 factors that influence slope stability (Carrara, 1983). Varnes and others (1984) and Brabb (1984) provide several examples of different susceptibility maps. Figure 4 shows a large-scale susceptibility map for an area near San Francisco, California.

Prediction and Warning

The analysis of slope stability and the design of systems to warn of a possible landslide have been the topics of many books and reports. The book edited by Schuster and Krizek (1978) provides an overview. Real-time regional landslide warning systems are rare, however, because of the complexities of landslide processes, the difficulty of determining the threshold values for triggering mechanisms, and the lack of real-time precipitation stations in landslide-prone areas. A debris-flow warning system has been developed recently (Keefer and others, 1987) for the San Francisco Bay region on the basis of empirical and analytical relations between rainfall and landslide generation, real-time monitoring of rainfall from 45 telemetering rain gauges, precipitation forecasts, and delineation of areas susceptible to landslide generation. Landslide warnings were issued twice in 1986 when cumulative and anticipated rainfall reached threshold values (fig. 5). The warnings were followed in both instances by debris flows and other landslides. The success of this warning system and analogy with other landslide processes indicate that real-time regional warning systems for different landslide processes are an attainable goal by the end of the International Decade for Natural Disaster Reduction.

Hazard Reduction

A general scheme for reducing the consequences of natural hazards has been provided by Kockelman (1990 and written comm., 1990).

"Programs having natural hazard reduction as a goal need five components, each a prerequisite for its successor:

- Conducting scientific and engineering studies of the physical processes of natural phenomena that may be hazardous—source, location, size, recurrence interval, severity, triggering mechanism, path, ground response, and structure response.

Table 2.—Selected examples of landslide damage and fatalities mentioned in newspapers, journals, professional reports, and magazine articles

Central America	
Costa Rica: 1967, debris flow from Irazu volcano killed 20 people, destroyed 300 houses, and caused $3.5 million in damages (U.S. Geological Survey Bulletin 1241-I, 1967) Mexico: Aug. 10, 1972, landslide killed four children near the southern Mexican town of Tuxtla Gutierrez (Washington Post, Aug. 11, 1972)	Guatemala: Feb. 4, 1976, an earthquake triggered at least 10,000 landslides that killed 200 people and damaged 500 homes (U.S. Geological Survey Prof. Paper 1204-A, 1981) El Salvador: Sept. 20, 1982, an estimated 500 people were killed and 25,000 made homeless from floods and landslides in the capitol and a 150-mile coastal belt (San Jose Mercury, Sept. 21, 1982)
South America	
Ecuador: Dec. 3, 1935, 27 people were killed within seconds when a landslide overwhelmed the village of Verde Cocha (New York Times, Dec. 4, 1935) Brazil: 1966 and 1967 storms killed as many as 2,700 people and "laid waste by landslides and fierce erosion a greater land mass than any ever recorded in geological literature." The power plant that served Rio de Janeiro suffered almost total destruction (U.S. Geological Survey Professional Paper 697) Colombia: Nov. 13, 1985, lahars from Nevada del Ruiz killed 22,000 people and destroyed $212 million in property (Eos, May 13, 1986)	Ecuador: Apr. 28, 1983, a landslide 250 miles south of Quito buried four cars and three buses, killing at least 100 people (New York Times, Apr. 29, 1983) Ecuador: Mar. 5, 1987, earthquake-triggered landslides and floods severed trans-Ecuadorian oil pipeline and the only highway from Quito to oil fields; $1.5 billion in damages (U.S. National Research Council Ground Failure Newsletter, spring 1988)
Europe	
Italy: Oct. 9, 1963, almost 3,000 people were killed when landslide fell into Vaiont Reservoir (Civil Engineering, March 1964) Austria: Nov. 20, 1964, a giant mudslide buried most houses in the Tyrolean village of Neu-Landl (Washington Daily News, Nov. 20, 1964) Austria: Nov. 5, 1966, rockslide killed nine people in Drau valley (Washington Post, Nov. 6, 1966) Portugal: 1967 and 1968, a landslide damaged approaches to the Salazar Bridge in Lisbon, requiring $1 million in repairs (Engineering News Record, July 11, 1970)	Italy: Dec. 13, 1982, 3,661 people evacuated and $600 million in damages, Ancona (U.S. National Research Council Ground Failure Newsletter, spring 1988) Italy: July 1985, failure of earthen embankment at Strava killed 206 people (Engineering News Record, July 25, 1985)
Middle East	
Turkey: 1969, repeated rockfalls plugged a diversion tunnel at Gokcekaya Dam, requiring a $1.5-million by-pass (Engineering News Record, Feb. 12, 1970) Turkey: Mar. 29, 1980, at least 64 people were killed by a landslide in the village of Ayvazhaci in central Turkey during two days of heavy rain (Washington Post, Mar. 30, 1980)	Iran: Mar. 25, 1983, about 90 motorists on a major Tehran-Caspian Sea highway were killed by rockfalls during an earthquake (San Juan Star, Mar. 27, 1983) Turkey: June 23, 1988, as many as 300 people were killed and several houses and a school were destroyed by a landslide in Catak northeast of Ankara (San Francisco Chronicle, June 24, 1988)
Africa	
Mozambique : Nov. 1973, six tunnel workers were killed by a rockfall (Engineering News Record, Nov. 22, 1973)	
Asia	
New Guinea: 1935, landslides triggered by earthquakes denuded 130 km^2 (8 percent of a 1,662 km^2 forested region (Science, Sept. 7, 1979) Nepal: Aug. 16, 1963, six villages 60 miles northwest of Kathmandu were buried by landslides, killing an estimated 150 people (Washington Post, Aug. 17, 1963) India : 1968, vast areas of Sikkim and West Bengal were destroyed by 20,000 landslides killing 33,000 people (R.K. Bhandari lecture notes, 1987) India: July 14, 1968, at least 15 persons, including 11 children, were killed by landslides in Kerala's western Kozhikod district (Washington Post, July 15, 1968)	New Guinea: Mar. 21, 1971, landslide in Star Mountains buried village killing 100 people (Washington Post, Mar. 22, 1971) Bangladesh: June 23, 1974, 39 people were killed and 50,000 left homeless in landslide and flood disaster (Washington Post, June 24, 1974) Nepal: June 6, 1976, the village of Pahire Phedi, 90 miles west of Kathmandu, was struck by a landslide, killing 150 people (Washington Post, June 9, 1976) India: Nov. 5, 1978, at least 125 people died in landslides and flash floods in southern Indian states of Tamil Nadu and Kerala (Washington Post, Nov. 6, 1978)

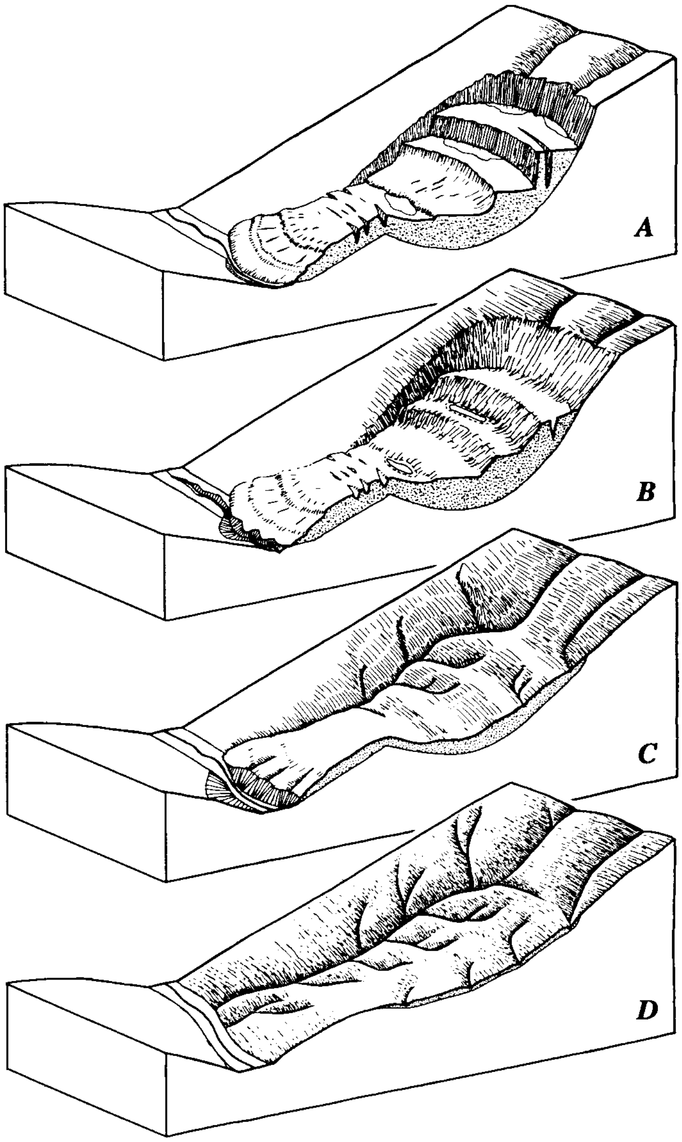


Figure 2.—Diagram showing how erosion modifies landslide deposits and makes them more difficult to recognize on aerial photographs (from McCalpin, 1984). **A**, *Active landslide with sharp features;* **B**, *Landslide features modified slightly by erosion;* **C**, *Landslide features modified extensively by erosion;* **D**, *Landslide features so modified by erosion that few, if any, can be recognized. Even the most extensively modified landslides may be active if erosion proceeds more rapidly than the landsliding. All landslides, even those that are extensively modified and inactive, may move again if their equilibrium is upset by the works of humans.*

- Translating the results of such studies into reports and onto maps so that the nature and extent of the hazards or their effects are understood by nontechnical users.
- Transferring this translated information to those who will or are required to use it and assisting them in its use through educational, advisory, and review services.
- Selecting and using appropriate hazard-reduction techniques—legislation, regulations, design criteria, financial incentives, and public or corporate policies.
- Reviewing the effectiveness of the hazard-reduction techniques after they have been in use for a requisite amount of time and revising as necessary. Review of the entire program as well as the other components—studies, translation, and transfer—may also be undertaken."

A practical guideline for planners incorporating these concepts for landslide hazard reduction has been prepared by Wold and Jochim (1989).

Publications and actions from a U.S. Geological Survey project in San Mateo County, California, near San Francisco, illustrate well the five components noted by Kockelman:

1. The occurrence of past landslides is shown on a landslide inventory map (fig. 6*B*). A geologic map (fig. 6A) and slope map (fig. 6C) are additional data sets used to prepare a landslide-susceptibility map.

2. The landslide-susceptibility map (fig. 6*D*) is a translated product in the sense of Kockelman in that it conveys in nontechnical language where landslides are most likely to be a problem in the future.

3. The landslide-susceptibility map and the basic data sets were transferred to the San Mateo County planning staff and decisionmakers on the Planning Commission and the Board of Supervisors by the U.S. Geological Survey scientists who prepared the maps.

4. The same scientists worked with the staff and decisionmakers in formulating ordinances and regulations to deal with landslide hazards. An ordinance was devised and adopted by the San Mateo County Board of Supervisors in 1973 to reduce the permitted density of housing in landslide-prone areas (categories VI and L on the map by Brabb and others (1972) to one dwelling unit per 16 hectares. In these same areas, a report by a registered geologist is required before any development is permitted. If the property owner feels that the landslide-susceptibility map is incorrect or too restrictive, he or she can employ a geologist to investigate the landslide potential and to petition the Board of Supervisors for a higher density. Very few property owners have taken advantage of this provision.

5. The density ordinance originally was applied only to part of the County. After several months of working with the mechanics of applying the ordinance and evaluating the effects, the staff proposed, and the Board of Supervisors accepted, extension of the ordinance to all unincorporated parts of the County. The landslide inventory and susceptibility maps were also evaluated and used in plans for open space, transportation corridors, public facilities, public safety ordinances, and emergency response.

The scientific aspects of the map have not held up as well as the political and planning aspects. For nearly 10 years after the map was prepared, all landslide activity occurred in the highest susceptibility categories. In 1982, however, an unusual combination of meteorological events produced rainfall intensities rarely recorded, and thousands of debris flows occurred in areas where few if any had been observed previously. Subsequent examination of aerial photographs revealed that debris flows were widespread in the County following heavy rains in 1955, but that in 1968, the date of the photography used for the 1972 map, most of the scars had been subdued by erosion and covered by vegetation. Some of them could have been recognized, but large, deep-seated landslides so dominated the literature and daily concerns in the 1960's that the more surficial debris flows were largely overlooked.

Earthquake-generated landslides were another process not taken into account in the preparation of the 1972 map because no methodology for making such a map existed at that time. Like debris flows, this process in San Mateo County mainly leaves scars that are eroded and covered with vegetation within a few years. Inasmuch as the last major earthquake was in 1906, little evidence for shallow landslides formed during that event could be seen on the 1968 photography. In order to correct that problem, Keefer and others (1979) and Wilson

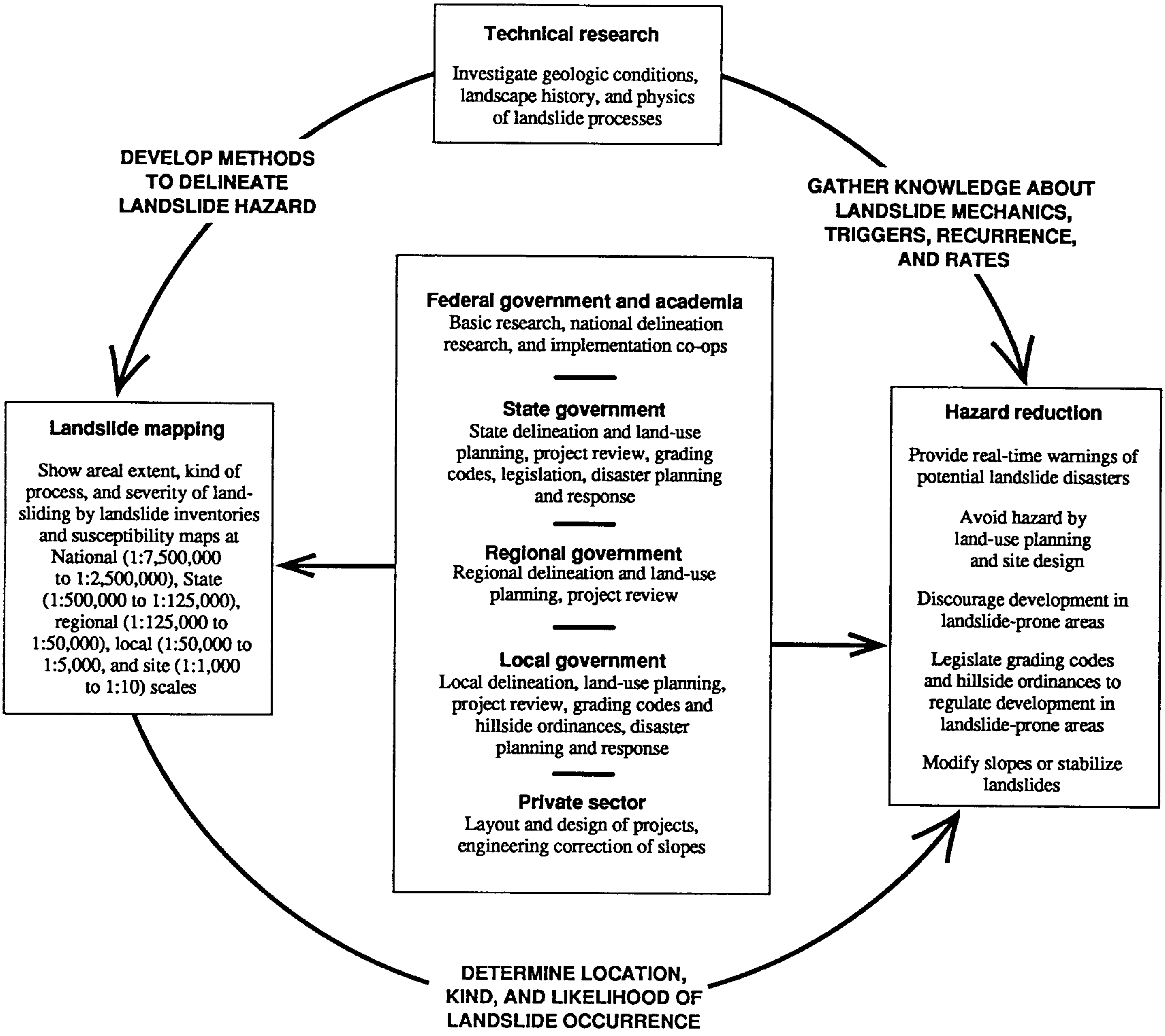


Figure 3.—Interaction between landslide research, mapping activities, and hazard reduction. Figure prepared by C.M. Wentworth, U.S. Geological Survey.

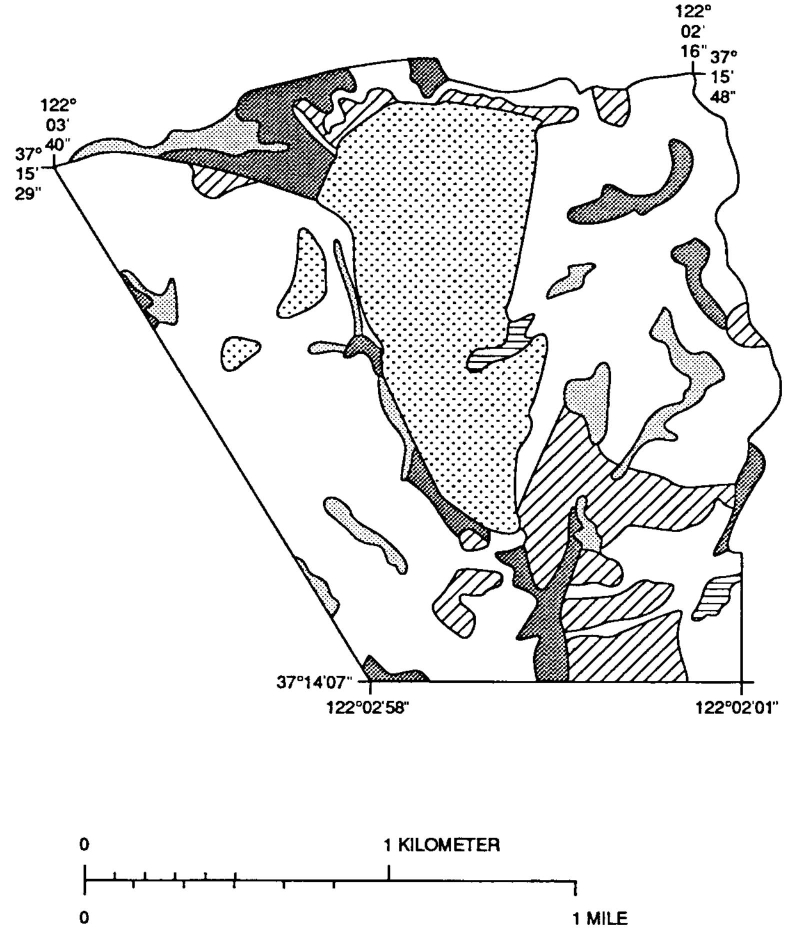
and Keefer (1983) developed a method to predict which areas would fail by landsliding during an earthquake; Wieczorek and others (1985) applied this method in preparing a new map for the County.

Kockelman (1986) has also provided many practical techniques and examples for reducing landslide hazards, as summarized in table 3. These techniques can be used in a variety of combinations to help solve both existing and potential landslide problems.

Landslide hazard reduction programs are being carried out in France (Flageollet, 1989), Canada (Cruden and others, 1989), Norway (Gregersen and Sandersen, 1989), Sweden (Viberg, 1989), Alpine countries of Europe (Swanston and Schuster, 1989), Czechoslovakia (Rybar and Novosad, 1989), Soviet Union (Ginzburg, 1989), southern Africa (Paige-Green, 1989), China (Li, 1989), Japan (Oyagi, 1989), Hong Kong (Brand, 1989), and New Zealand (Blong and Eyles, 1989).

Program Funding

Experiences in Los Angeles indicate that landslide losses can be reduced by more than 90 percent by requiring soil and geologic reports, inspections and approvals throughout the grading process, and final certification of completed earthwork by the city engineer (Jahns, 1978; Fleming and others, 1979). Applying the resulting



RELATIVE STABILITY	MAP AREA	GEOLOGIC CONDITIONS	RECOMMENDED LAND USE Houses	Roads Public	Roads Private
Most stable	▓	Flat to gentle slopes; subject to local shallow sliding, soil creep, and settlement	Yes	Yes	Yes
	▤	Gentle to moderately steep slopes in older stabilized landslide debris; subject to settlement, soil creep, and shallow and deep landsliding	Yes*	Yes*	Yes*
	░	Steep to very steep slopes; subject to mass-wasting by soil creep, slumping, and rock fall	Yes*	Yes*	Yes*
	☐	Gentle to very steep slopes in unstable material subject to sliding, slumping, and soil creep	No*	No*	No*
	▨	Moving, shallow (>10 ft) landslide	No*	No*	No*
Least stable	⁘	Moving, deep landslide, subject to rapid failure	No	No	No

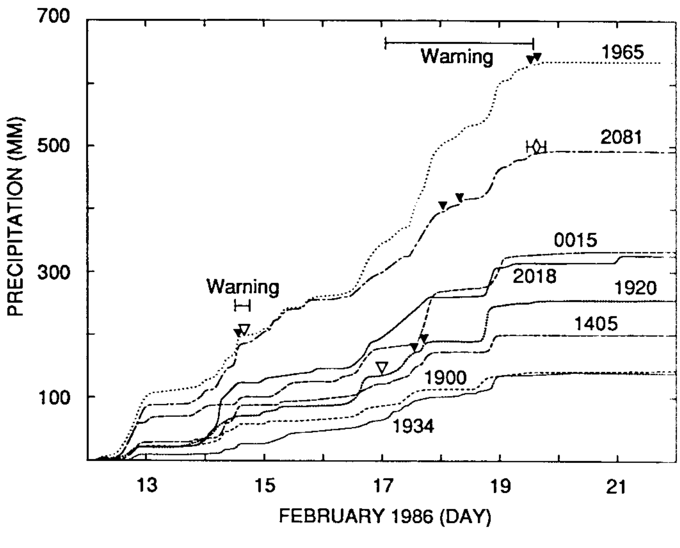
EXPLANATION

Yes* The land use would normally be expected to be permitted, provided the geologic data and (or) engineering solutions are favorable. However, there will be instances where the use will not be appropriate

No* The land use would normally not be permitted. However, there will be circumstances where geologic data and (or) engineering solutions will permit the use

Figure 4.—Landslide susceptibility map and recommended land-use policies for the Congress Springs area near San Francisco. California. Original map at a scale of 1:3,000 shows roads, houses, and other cultural features. (From Cotton and Associates, 1977).

Figure 5.—Cumulative precipitation recorded by some of the telemetered rain gauges in the San Francisco Bay region in and near landslide areas during storms of 12 to 21 February, 1986. Landslide warnings were issued during the times shown by horizontal bars. The times of landslides reported by eyewitnesses are shown by diamonds (slumps), filled triangles (debris flows), and open triangles (undetermined types). Landslides are plotted on the trace of the nearest rain-gauge record. (From Keefer and others, 1987).



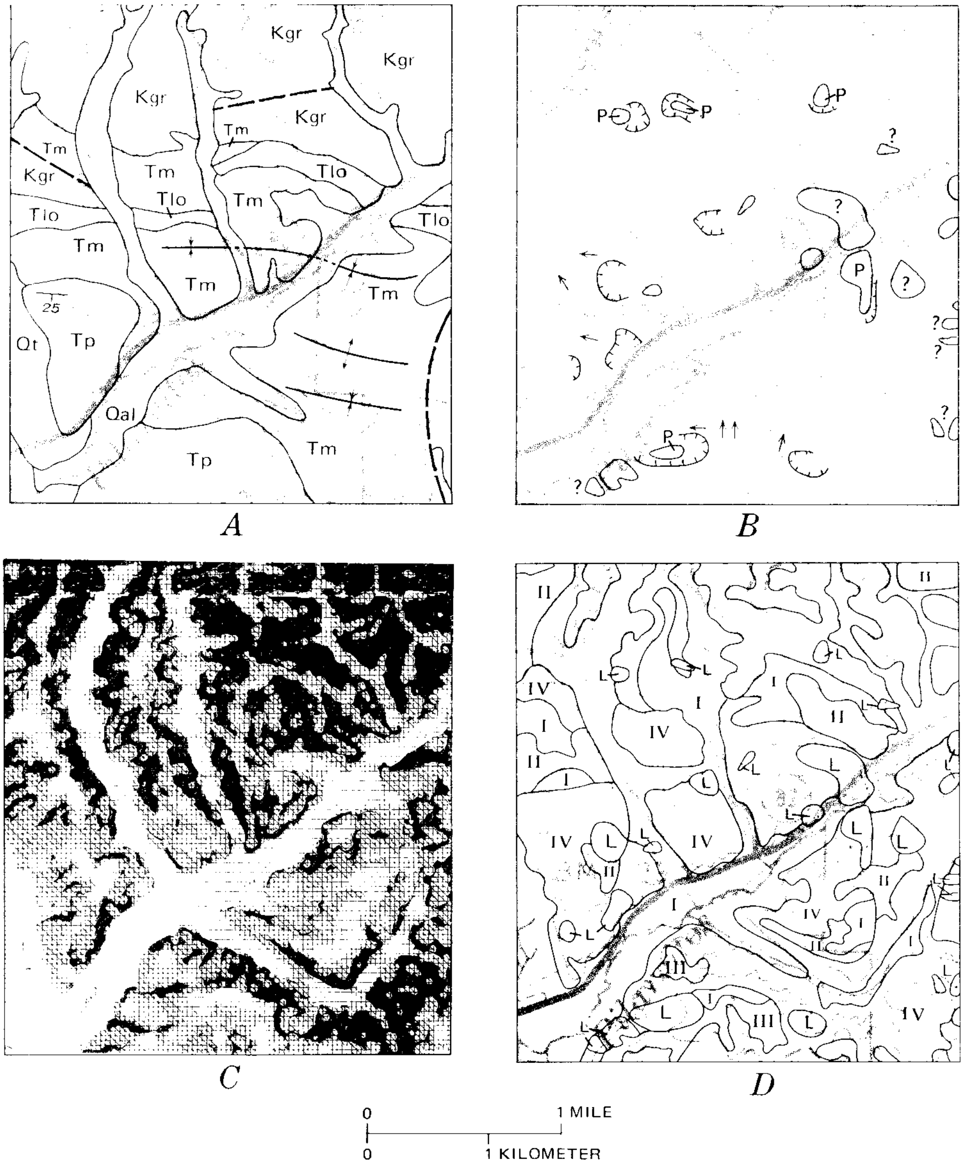


Figure 6.—Materials used for a landslide-susceptibility map of San Mateo County, California. Area shown is near the town of La Honda, about 25 km south of San Francisco. **A**, *Geologic map, including granitic rocks of Cretaceous age (Kgr), shale and sandstone units of Miocene and Pliocene Age (Tp, Tm, Tlo), terrace deposits (Qt), and alluvium (Qal). Heavy dashed lines are faults; thinner lines with arrows are fold axes. (From Brabb and Pampeyan, 1972a).* **B**, *Landslide map. Small arrows show landslide deposits 15 to 150 m in largest dimension, and other lines show landslides larger than 150 m; hachured lines show landslide scarps. P, probable landslide deposit; ?, questionable landslide deposit. (From Brabb and Pampeyan, 1972b).* **C**, *Slope map. Darker tone indicates greater slope. (From Mark and others, 1988).* **D**, *Landslide-susceptibility map. Higher Roman numeral indicates greater susceptibility. Landslide deposits (L) are shown as a separate category (highest). (From Brabb and others, 1972).*

Table 3.—Some techniques for reducing landslide hazards. From Kockelman (1986)

- Discouraging new development in hazardous areas by:
  - Disclosing the hazard to real-estate buyers
  - Posting warnings of potential hazards
  - Adopting utility and public-facility service-area policies
  - Informing and educating the public
  - Making a public record of hazards
- Removing or converting existing development through:
  - Acquiring or exchanging hazardous properties
  - Discontinuing nonconforming uses
  - Reconstructing damaged areas after landslides
  - Removing unsafe structures
  - Clearing and redeveloping blighted areas before landslides
- Providing financial incentives or disincentives by:
  - Conditioning federal and state financial assistance
  - Clarifying the legal liability of property owners
  - Adopting lending policies that reflect risk of loss
  - Requiring insurance related to level of hazard
  - Providing tax credits or lower assessments to property owners
- Regulating new development in hazardous areas by:
  - Enacting grading ordinances
  - Adopting hillside-development regulations
  - Amending land-use zoning districts and regulations
  - Enacting sanitary ordinances
  - Creating special hazard-reduction zones and regulations
  - Enacting subdivision ordinances
  - Placing moratoriums on rebuilding
- Protecting existing development by:
  - Controlling landslides and slumps
  - Controlling mudflows and debris flows
  - Controlling rockfalls
  - Creating improvement districts that assess costs to beneficiaries
  - Operating monitoring, warning, and evacuating systems

savings to the $1.5 billion in estimated annual landslide costs in the United States (Schuster and Fleming, 1986), programs costing more than $1 billion to reduce landslide damage would be cost effective and are sorely needed. The cost effectiveness of specific actions, however, must be determined for each case. For example, Bernknopf and others (1988) determined that applying the Uniform Building Code to the Cincinnati, Ohio, area would be cost-effective only if factors that control landslide distribution, such as geology and slope, are taken into account and the regulated area reduced in size to the most vulnerable parts.

No figures are available for the total cost of reducing landslide damage in the United States, but only $5 million or less is available for landslide research, according to the U.S. Committee on Ground Failure Hazards (1985). Hong Kong spends about twice that amount annually on geotechnical studies and landslide-preventive works (Brand, 1989). Japan spends a maximum annually of about $33 million to rescue people from landslides; $300 million to restore railroads, bridges, dams, and other public facilities damaged by landslides; $617 million to control slow-moving landslides designated since 1958 as problem areas; and more than $2 billion to repair and control other landslides (Oyagi, 1989). Most other countries spend very little for landslide research or mitigation, judging from reports in the book edited by Brabb and Harrod (1989).

Policy Options

There are many policy options available to decisionmakers for dealing with landslide problems, as discussed in reports by Petak and Atkisson (1982), Olshansky and Rogers (1987), and Rossi and others (1982). Although these policy options relate only to the United States, many would apply to other countries. Rossi and others (1982) indicate that:

1. Political decisionmakers in the States and local communities do not see environmental hazards as a very serious problem, particularly in comparison to problems like welfare, unemployment, and crime.
2. The best predictor of the seriousness attributed to hazard problems is prior experience with disasters.
3. Neither prior experience with disasters nor the seriousness attributed to disasters predicts policy preferences, contrary to what might be expected. An interesting corollary is that hazard-reduction measures may be more difficult to implement in states with the most serious hazard problems.
4. Policy innovation and directives are more likely to originate at the Federal level.
5. Traditional policies of structural mitigation and postdisaster relief represent the majority view for the most appropriate policy responses.
6. Hazard specialists generally favor nonstructural mitigation measures—real estate and land-development interests strongly favor more traditional policies. Decisionmakers lie in between and will move in whatever direction seems politically expedient.

Geographic Information Systems

One development that may favorably influence the policy options available for coping with landslide hazards is Geographic Information Systems (GIS). A GIS uses a spatial data base, usually in digital form, to solve geographical problems, such as the relation between landslide distribution and geologic units. The methodology for making landslide-susceptibility maps used by Brabb and others (1972) in San Mateo County, for example, is readily adaptable to computer analysis (Newman and others, 1978) and quick and inexpensive production of high-resolution color images. The general procedures are outlined in fig. 7. As more data sets become available in digital form, especially geologic and slope information, the tasks required to prepare landslide hazard maps that decisionmakers will understand and use will become easier.

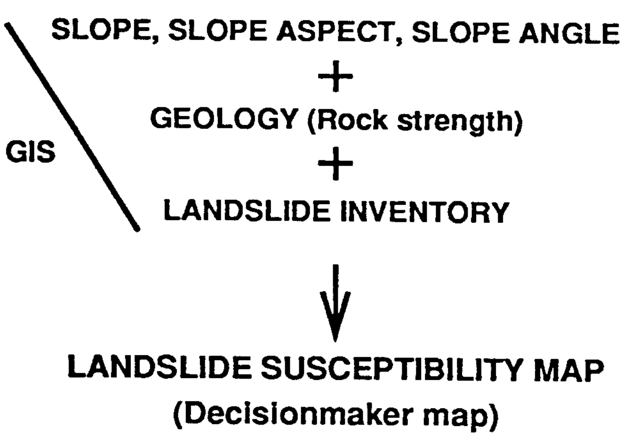


Figure 7.—Steps involved in making a landslide-susceptibility map by Geographic Information Systems (GIS) procedures. See report by Newman and others (1978) for details.

Landslide Workshops and Meetings

The International Society for Soil Mechanics and Foundation Engineering holds a symposium on landslides every 4 years. The proceed-savings to the $1.5 billion in estimated annual landslide costs in the ings of the 1988 meeting in Lausanne are 1,564 pages long, the single most important reference for landslide activities in many countries. In Italy, the National Group for Prevention of Hydrogeological Hazards, a subgroup of the National Research Council, conducts an annual 4-week workshop on landslide and flood hazards in cooperation with the Water Resources Research Center of the Italian University for Foreigners and the U.S. Geological Survey. In Guatemala, the Swedish International Development Authority funds a center to provide courses and field work on landslides each year. In other Latin American countries, the Organization of American States periodically conducts courses on natural hazards mitigation. In Europe, the Council of Europe has organized a summer university on the subject of natural risks, including landslides; the first session was held in Sion, Switzerland, during September 1990. Also in Europe, the 5th International Conference and Field Workshop on Landslides met in Switzerland, Italy, and Austria in September 1990 to discuss landslides in a field environment. Proceedings from this and previous meetings provided much new information on landslide processes.

Conclusions

Landsliding is a worldwide problem that probably results in thousands of deaths and tens of billions of dollars of damage each year. Much of this loss would be avoidable if the problem were recognized early, but less than one percent of the world has landslide-inventory maps that show where landslides have been a problem in the past, and even smaller areas have landslide-susceptibility maps that show the severity of landslide problems in terms decisionmakers understand. Landslides are generally more manageable and predictable than earthquakes, volcanic eruptions, and some storms, but only a few countries have taken advantage of this knowledge to reduce landslide hazards.

Landsliding is likely to become more important to decisionmakers in the future as more people move into urban areas in mountain environments and as the interaction between deforestation, soil erosion, stream-habitat destruction, and landsliding becomes more apparent.

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