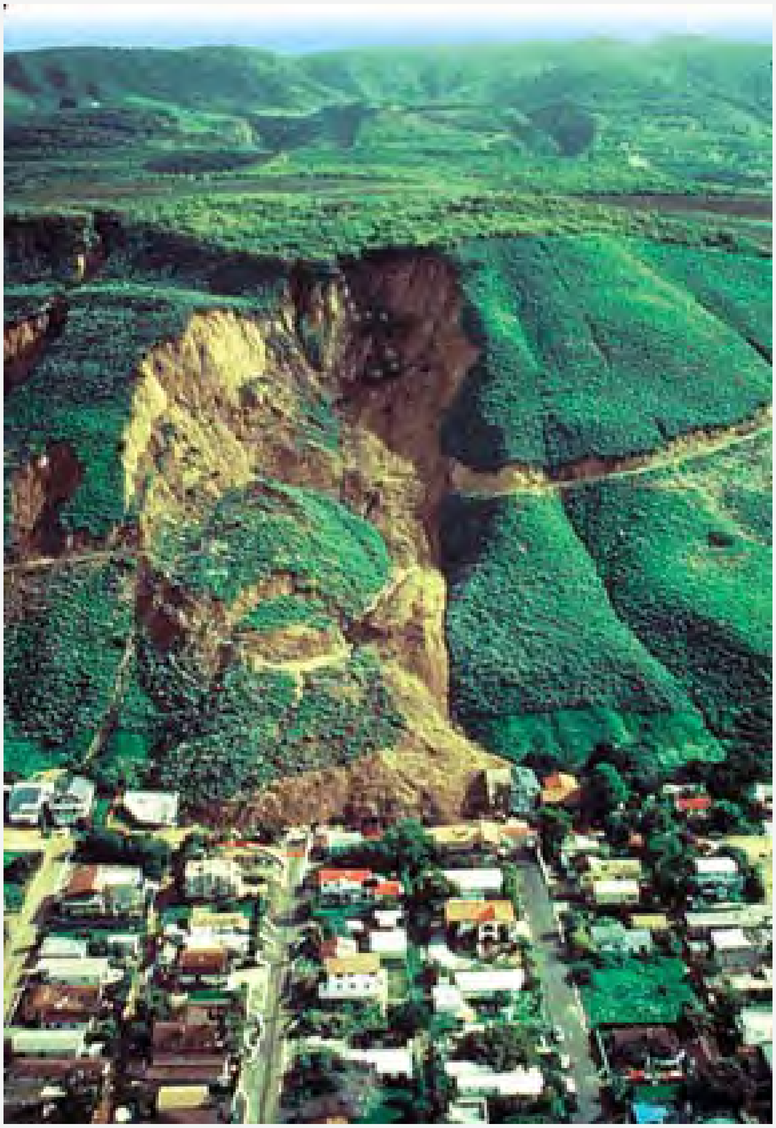
National Landslide Hazards Mitigation Strategy— A Framework for Loss Reduction



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U.S. Department of the Interior
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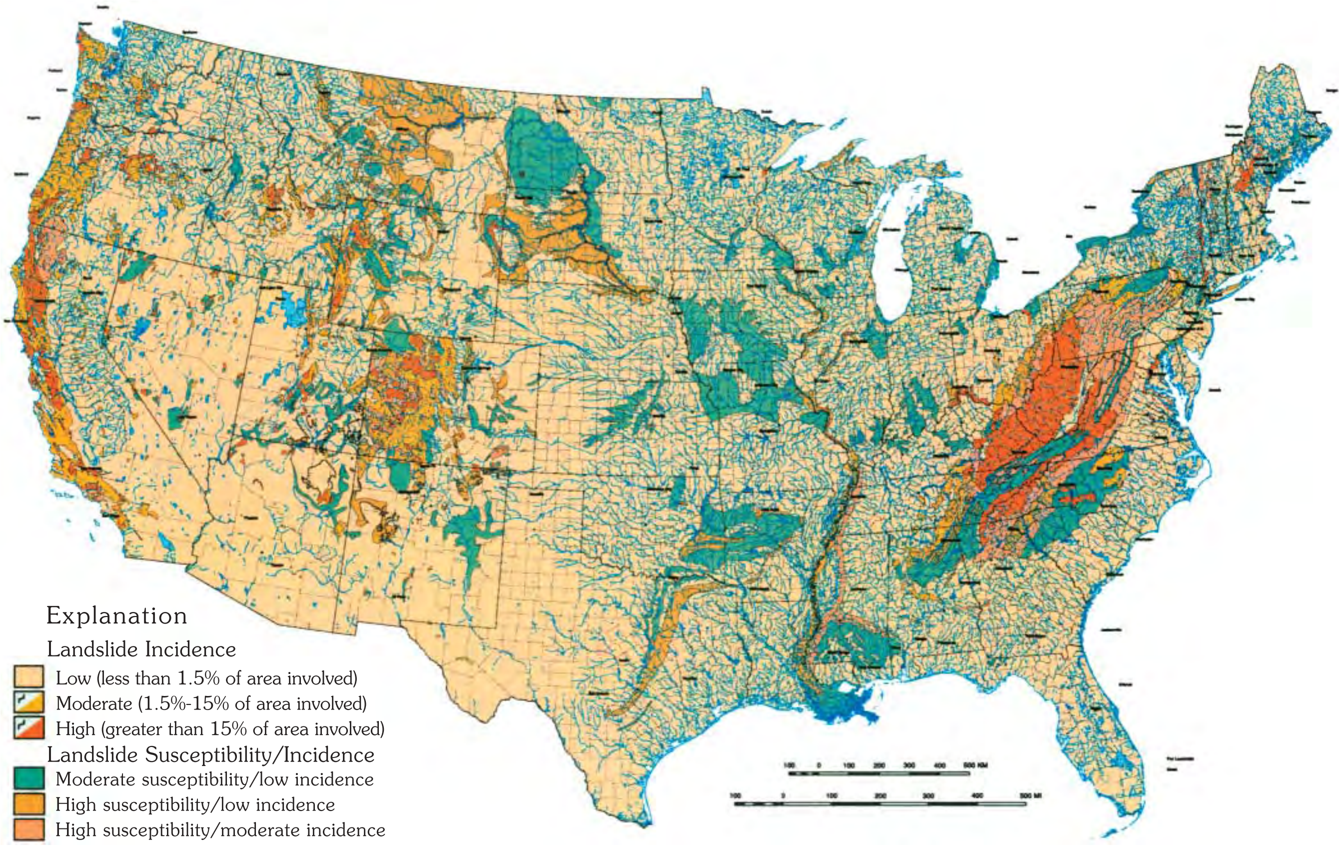

Landslide overview map of the conterminous United States. Different colors denote areas of varying landslide occurrence. From U.S. Geological Survey, 1997, Digital compilation of landslide overview map of the conterminous United States: U.S. Geological Survey Open-File Report 97–0289, digital compilation by Jonathan W. Godt, available on the web at http://greenwood.cr.usgs.gov/pub/open-file-reports/ofr-97-0289/.

Front cover. Massive landslide at La Conchita, California, a small seaside community along Highway 101 north of Santa Barbara. This landslide and debris flow occurred in the spring of 1995. Many people were evacuated because of the slide, and the houses nearest the slide were completely destroyed. Fortunately, no one was killed or injured. Photograph by R.L. Schuster, U.S. Geological Survey.

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By Elliott C. Spiker and Paula L. Gori

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Preface

House Report 106–222 accompanying the Interior Appropriations Bill for fiscal year 2000 (as incorporated in Public Law 106–113) states, "The committee is concerned over the lack of attention given to the Survey's landslide program. Because of this concern, the Survey is directed to develop by September 15, 2000, a comprehensive strategy, including the estimated costs associated with addressing the widespread landslide hazards facing the Nation. The preparation of this strategy should include the involvement of all parties having responsibility for dealing with the problems associated with landslides."

In fulfillment of the requirements of Public Law 106–113, the United States Geological Survey submits this circular, which describes a national strategy to reduce losses from landslides. The circular includes a summary of the Nation's needs for research, monitoring, mapping, and assessment of landslide hazards nationwide.

Contents

Highlights

Figures

Table

National Landslide Hazards Mitigation Strategy— A Framework for Loss Reduction

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"Science by itself will not protect us. Federal, State, and local governments, the private sector, volunteer and charitable organizations and individual citizens must work together in applying the science to make our communities safer."

—Charles Groat, Director of the U.S. Geological Survey

Executive Summary

This circular outlines the key elements of a comprehensive and effective national strategy for reducing losses from landslides nationwide and provides an assessment of the status, needs, and associated costs of this strategy. The circular is submitted in compliance with a directive of Public Law 106–113 (see preface). A broad spectrum of expert opinion was sought in developing this strategy report, as requested by the U.S. Congress in House Report 106–222.

The strategy was developed in response to the rising costs resulting from landslide hazards in the United States and includes activities at the National, State, and local levels, in both the public and private sectors. The strategy gives the Federal Government a prominent role in efforts to reduce losses due to landslide hazards, in partnership with State and local governments. The U.S. Geological Survey (USGS) has taken the lead in developing the strategy on behalf of the large multisector, multiagency stakeholder group involved in landslide hazards mitigation. The USGS derives its leadership role in landslide hazard-related work from the Disaster Relief Act of 1974 (Stafford Act). For example, the Director of the USGS has been delegated the responsibility to issue disaster warnings for an earthquake, volcanic eruption, landslide, or other geologic catastrophe (1974 Disaster Relief Act 42 U.S.C. 5201 et seq).

The National Landslide Hazards Mitigation Strategy includes developing new partnerships among government at all levels, academia, and the private sector and expanding landslide research, mapping, assessment, real-time monitoring, forecasting, information management and dissemination, mitigation tools, and emergency preparedness and response. Such a strategy uses new technological advances, enlists the expertise associated with other related hazards such as floods, earthquakes and volcanic activity, and utilizes incentives for the adoption of loss reduction measures nationwide.

The strategy envisions a society that is fully aware of landslide hazards and routinely takes action to reduce both the risks and costs associated with those hazards. The long-term mission of a comprehensive landslide hazard mitigation strategy is to provide and encourage the use of scientific information, maps, methodology, and guidance for emergency management, land-use planning, and development and implementation of public and private policy to reduce losses from landslides and other ground-failure hazards nationwide. The 10-year goal is to substantially reduce the risk of loss of life, injuries, economic costs, and destruction of natural and cultural resources that result from landslides and other ground-failure hazards.

This comprehensive National Landslide Hazards Mitigation Strategy employs a wide range of scientific, planning, and policy tools to address various aspects of the problem to effectively reduce losses from landslides and other ground failures. It has the following nine major elements, spanning a continuum from research to the formulation and implementation of policy and mitigation:

- Research.—Developing a predictive understanding of landslide processes and triggering mechanism
- Hazard mapping and assessments.—Delineating susceptible areas and different types of landslide hazards at a scale useful for planning and decisionmaking
- Real-time monitoring.—Monitoring active landslides that pose substantial risk
- Loss assessment.—Compiling and evaluating information on the economic impacts of landslide hazards
- Information collection, interpretation, and dissemination.—Establishing an effective system for information transfer
- Guidelines and training.—Developing guidelines and training for scientists, engineers, and decisionmakers
- Public awareness and education.—Developing information and education for the user community
- Implementation of loss reduction measures.—Encouraging mitigation action
- Emergency preparedness, response, and recovery.—Building resilient communities

In each of the above nine elements above, the USGS has a significant role; however, the USGS is not the lead for all elements.

Landslide hazards mitigation requires collaboration among academia, government, and the private sector. Aggressive implementation of a comprehensive and effective national landslide hazards mitigation strategy requires increased investment in landslide hazard research, mapping and monitoring, and mitigation activities. Reducing losses from landslide hazards can be accomplished in part by expanding the existing USGS Landslide Hazard Program, as follows:

- Expansion of research, assessment, monitoring, public information, and response efforts by USGS scientists ($8 million annually)
- Establishment of a Cooperative Landslide Hazard Assessment and Mapping Program to increase the efforts of State and local governments to map and assess landslide hazards within their jurisdictions through competitive grants ($8 million annually, to be augmented with 30 percent matching funds by the States and local jurisdictions)
- Establishment of a Cooperative Federal Land Management Landslide Hazard Program to increase the capability of the National Park Service, U.S. Forest Service, Bureau of Land Management, and other such organizations to address landslide hazards under their jurisdictions ($2 million annually for work performed by USGS scientists on public lands)
- Establishment of a Partnerships for Landslide Hazard Loss Reduction Program to support research and implementation efforts by universities, local governments, and the private sector through competitive grants ($2 million annually)

Total new funding required for full implementation of the National Landslide Hazards Mitigation Strategy within the USGS is estimated to be approximately $20 million annually.

An effective National Landslide Hazards Mitigation Strategy also depends on stronger partnerships among Federal, State, and local governments and the private sector in the areas of hazard assessments, monitoring, and emergency response and recovery. The strategy recommended in this circular advocates enhanced coordination among Federal, State, and local agencies to partner effectively with the academic and the private sectors and to leverage shared resources under the leadership of the USGS.

Introduction

Landslides and other forms of ground failure affect communities all across the Nation. Despite advances in science and technology, these events continue to result in human suffering, billions of dollars in property losses, and environmental degradation. As our population increases and our society becomes ever more complex, the economic and societal costs of landslides and other ground failures will continue to rise.

We have the capability as a Nation to understand and identify these hazards and to implement mitigation measures. For many years, the U.S. Geological Survey (USGS), the States, numerous universities, and the private sector have been grappling with understanding and reducing landslide hazards, and they have developed an extensive body of knowledge (see appendix 1 for sources of information). However, to achieve the goal of significantly reducing losses from landslide hazards, we need a much more comprehensive scientific understanding of landslide processes and occurrence, a robust monitoring program to warn of impending danger from active landslides, a much greater public awareness and understanding of the threat and the options for reducing the risk, and action at the local level.

A significant, sustained, long-term effort to reduce losses from landslides and other ground failures in the United States will require a national commitment among all levels of government and the private sector. The Federal Government, in partnership with State and local governments, must provide leadership, coordination, research support, incentives, and resources to encourage communities, businesses, and individuals to undertake mitigation to minimize potential losses and to employ mitigation in the recovery following landslides and other natural hazard events.

The USGS is the recognized authority for understanding landslide hazards in the United States and the long-time leader in this area. The USGS derives its leadership role in landslide-hazard-related work from the Disaster Relief Act of 1974 (Stafford Act). The Director of the USGS has been delegated the responsibility to issue disaster warnings for an earthquake, volcanic eruption, landslide, or other geologic catastrophe consistent with the 1974 Disaster Relief Act 42 U.S.C. 5201 et seq.

As requested by the U.S. Congress in House Report 106–222, the USGS has prepared this National Landslide Hazards Mitigation Strategy on behalf of the large multisector, multiagency stakeholder group involved in landslide research and mitigation nationwide. A number of stakeholder workshops were held during 1999 and 2000 with representatives of government and private organizations, academicians, and private citizens to seek their opinion and input (see appendix 2 for more information about the stakeholder workshops).

Highlight 1—
Massive Landslide at Thistle, Utah

The 1983 Thistle landslide began moving in the spring of 1983 in response to ground-water buildup from heavy rains the previous September and melting snowpack from the winter of 1983. Within a few weeks, the landslide dammed the Spanish Fork River, consequently obliterating U.S. Highway 6 and the main line of the Denver and Rio Grande Western Railroad (fig. 1).

The town of Thistle was inundated by the floodwaters rising behind the landslide dam. Eventually a drain system was engineered to drain the lake and avert a potential disaster. The landslide reached a state of equilibrium across the valley, but fears of reactivation caused the railway to construct a tunnel through bedrock around the slide zone at a cost of millions of dollars. The highway likewise was realigned around the landslide. When the lake was drained, residual muck partially buried the town, and virtually no one returned to Thistle. Total costs (direct and indirect) incurred by this landslide exceeded $400 million, making this the most costly single landslide event in U.S. history.

Figure 1. The 1983 Thistle landslide, central Utah. Thistle Lake, which resulted from damming of the Spanish Fork River, was later drained as a precautionary measure. This view, taken about 6 months after the slide occurred, shows the realignment of the Denver and Rio Grande Western Railroad lines in the lower center and the large cut for rerouting U.S. Highway 6/50 on the extreme left side of the photograph.
Photograph by R.L. Schuster, U.S. Geological Survey.

The National Landslide Hazards Mitigation Strategy provides a framework for reducing losses from landslides and other ground failures. Although the strategy is national in scope, it is not exclusively Federal or even exclusively governmental. Mitigation, defined as any sustained action taken to reduce and eliminate long-term risk to life and property, generally occurs at the State and local levels, and the strategy is based on partnerships with stakeholders at all levels of government and in the private sector.

The National Landslide Hazards Mitigation Strategy described here incorporates many ideas and recommendations of previous studies and reports that expressed the need for a national strategy to address natural hazards, including landslides and other ground failures (see appendix 1). These earlier studies and reports should be referred to for more in-depth discussions of and insights into landslide hazard mitigation and research needs. The National Landslide Hazards Mitigation Strategy builds on the principles, goals, and objectives of the National Mitigation Strategy—Partnerships for Building Safer Communities, developed in 1996 by the Federal Emergency Management Agency (FEMA) to encourage mitigation of all forms of natural hazards in the United States.

The term "landslide" describes many types of downhill earth movements, ranging from rapidly moving catastrophic rock avalanches and debris flows in mountainous regions to more slowly moving earth slides and other ground failures. In addition to the different types of landslides, the broader scope of ground failure includes subsidence, permafrost, and shrinking soils. This report focuses on landslides, the most critical ground-failure problem facing most regions of the Nation. However, the National Landslide Hazards Mitigation Strategy provides a framework that can be applied to other ground-failure hazards (see appendix 3 for more information about different types of landslide hazards and other forms of ground failure).

Losses from Landslide Hazards in the United States

Landslides are among the most widespread geologic hazards on Earth. Landslides cause billions of dollars in damages and thousands of deaths and injuries each year around the world. Landslides threaten lives and property in every State in the Nation, resulting in an estimated 25 to 50 deaths and damage exceeding $2 billion annually. Although most landslides in the United States occur as separate, widely distributed events, thousands of landslides can be triggered by a single severe storm and earthquake, causing spectacular damage in a short time over a wide area.

The United States has experienced several catastrophic landslide disasters in recent years. In 1985, a massive slide in southern Puerto Rico killed 129 people, the greatest loss of life from a single landslide in U.S. history. The 1982–83 and 1983–84 El Niño seasons triggered landslide events that affected the entire Western United States, including California, Washington, Utah, Nevada, and Idaho. The Thistle, Utah, landslide of 1983 caused $400 million in losses, the most expensive single landslide in U.S. history, and the 1997–98 El Niño rainstorms in the San Francisco Bay area produced thousands of landslides, causing over $150 million in direct public and private costs.

Landslides are a significant component of many major natural disasters and are responsible for greater losses than is generally recognized. Landslide damage is often reported as a result of a triggering event—floods, earthquakes, or volcanic eruptions—even though the losses from landsliding may exceed all other losses from the overall disaster. For example, flash floods in mountainous areas often have devastating debris flows. Also, most of the losses due to the 1964 Alaska earthquake resulted from ground failure rather than from shaking of structures, and landslides associated with a major earthquake in Afghanistan and with Hurricane Mitch in Central America in 1998 caused the majority of fatalities in these disasters.

All 50 States and the U.S. Territories experience landslides and other ground-failure problems; 36 States have moderate to highly severe landslide hazards. The greatest landslide damage occurs in the Appalachian, Rocky Mountain, and Pacific Coast regions and Puerto Rico. Seismically active mountainous regions, such as those in Alaska, Hawaii, and the West Coast are especially at risk. Extremely vulnerable are areas where wildfires have destroyed vegetation, exposing barren ground to heavy rainfall.

Landslide losses are increasing in the United States and worldwide as development expands under pressures of increasing populations. The resulting encroachment of developments into hazardous areas, expansion of transportation infrastructure, deforestation of landslide-prone areas, and changing climate patterns may lead to continually increasing landslide losses. However, an increase in the cost of landslide hazards can be curbed through better understanding and mapping of the hazards and improved capabilities to mitigate and respond to the hazards.

Highlight 2—
Wildfires and Debris Flows

During the summer of 2000, numerous wildfires burned drought-parched areas of the Western United States. U.S. Geological Survey (USGS) scientists were enlisted to advise Federal and State emergency response teams on the potential for future debris flows in burned areas, such as the Cerro Grande fire (Los Alamos, New Mexico) and the Hi-Meadow and Bobcat fires (Colorado).

Debris flows often occur during the fall and winter following major summer fires. One such combination of fires and debris flows occurred in July 1994, when a severe wildfire swept Storm King Mountain west of Glenwood Springs, Colorado, denuding the slopes of vegetation. Heavy rains on the mountain the following September caused numerous debris flows, one of which blocked Interstate 70 and threatened to dam the Colorado River (fig. 2). A 3-mile length of the highway was buried under tons of rock, mud, and burned trees. The closure of Interstate 70 imposed costly delays on this major transcontinental highway. The USGS assisted in analyzing the debris-flow threat and installing monitoring and warning systems to alert local safety officials when high-intensity rainfall occurred or debris flows passed through a susceptible canyon. Similar debris flows threaten other transportation corridors and other development in and near fire-ravaged hillsides.

From Highland, L.M., Ellen, S.D., Christian, S.B., and Brown, W.M., III, 1997, Debris-flow hazards in the United States: U.S. Geological Survey Fact Sheet FS–176–97, available on the web at http://geohazards.cr.usgs.gov/factsheets/debrisflowfs.pdf.

Figure 2. Debris flows like this one near Glenwood Springs, Colorado, in 1994 are a consequence of heavy rainfall on previously burned hillsides. In addition to personal injuries and damage to 30 vehicles engulfed by these flows, transportation along the Interstate 70 corridor was brought to a standstill for a day, and business and emergency operations in the Glenwood Springs area were seriously impeded. Photograph by Jim Scheidt, U.S. Bureau of Land Management.

Landslides and other ground failures impose many direct and indirect costs on society. Direct costs include the actual damage sustained by buildings and property, ranging from the expense of cleanup and repair to replacement. Indirect costs are harder to measure and include business disruption, loss of tax revenues, reduced property values, loss of productivity, losses in tourism, and losses from litigation. The indirect costs often exceed the direct costs. Much of the economic loss is borne by Federal, State, and local agencies that are responsible for disaster assistance and highway maintenance and repair.

Landslides have a significant adverse effect on infrastructure and threaten transportation corridors, fuel and energy conduits, and communications linkages. Ground-failure events have devastating economic effects on Federal, State, local, and private roads, bridges, and tunnels every year. Railroads, pipelines, electric and telecommunication lines, dams, offshore oil and gas production facilities, port facilities, and waste repositories continually are affected by land movement. Road building and construction often exacerbate the landslide problem in hilly areas by altering the landscape, slopes, and drainages and by changing and channeling runoff, thereby increasing the potential for landslides. Landslides and others forms of ground failure also have adverse environmental consequences, such as dramatically increased soil erosion, siltation of streams and reservoirs, blockage of stream drainages, and loss of valuable watershed, grazing, and timber lands.

Highlight 3—**Building Disaster-Resistant Communities**

An outstanding example of public-private partnerships is the Federal Emergency Management Agency's (FEMA) Disaster-Resistant Communities project (formerly called Project Impact). Nearly 200 communities and more than 1,100 business partners have embraced this project since its inception in 1997. Rather than waiting for disasters to occur, communities take action to reduce potentially devastating disasters. Seattle Washington, a city that is exposed to significant landslide hazards, was one of the first communities in the United States to join.

In conjunction with FEMA, the city of Seattle collaborated with the U.S. Geological Survey (USGS) to develop landslide hazard maps that will enable the city to be better prepared for landslide emergencies and to reduce losses resulting from landslide disasters (fig. 3). The city made available information needed by USGS scientists to accurately assess landslide hazards in the area and to produce a computer-based landslide hazard map. This map includes Seattle's detailed topographic database and related geographic data, detailed precipitation data collected by the National Weather Service, geographic information system support for completing the maps, and a landslide database from city records that date back to the late 1800s. USGS scientists are analyzing city data along with other information to determine the degree of landslide hazard throughout the city. The scientists are also conducting studies to determine the probability that landslides will result from storms of different magnitudes.

The Disaster-Resistant Communities project has resulted in unprecedented awareness of landslide hazards by the private sector. For example, major mortgage bankers have realized that they hold mortgages on many properties in areas of significant landslide hazard in Seattle and elsewhere in the United States and are beginning to take steps to encourage homeowners to mitigate the hazards.

Figure 3. Landslide in northwest Seattle, Washington. Foundation of the house on the right edge of the photograph and the decks of neighboring houses have been undermined. Photograph by Alan F. Chleborad, U.S. Geological Survey.

Society is far from helpless in the face of these prospects. Improvements in our scientific understanding of landslides and other ground-failure hazards can provide more accurate delineation of hazardous areas and assessments of their hazard potential. This information can be developed in a form and at a scale meaningful and useful for decisionmaking. Cost-effective actions can be taken to reduce the loss of lives and property, damage to the environment, and economic and social disruption caused by landslides and other ground failures (see appendix 4 for more information about mitigation techniques).

Government at all levels plays critical roles in advancing landslide hazard mitigation and developing programs and incentives that encourage and support community-based implementation. A national strategy to reduce losses from landslides and other ground failures must have both research and implementation components to increase understanding of landslides and other ground failures and put existing knowledge to use to reduce losses. Developing durable and comprehensive solutions to landslides and other ground-failure hazards will require a continuing dialog among and concerted action by all sectors of our society.

A new public-private partnership is needed at the Federal, State, and local levels to foster continuing cooperation among geologists, engineers, hydrologists, planners, and decisionmakers regarding landslides and other natural hazards. This ongoing effort will, over time, help to ensure that the needed scientific and engineering information is developed in a form useful for planning and decisionmaking and that such information is applied to mitigate these hazards.

Highlight 4—
Debris-Flow Flume—Understanding Landslide Processes

U.S. Geological Survey (USGS) and U.S. Forest Service (USFS) scientists recreate debris flows in a flume that has been constructed to conduct controlled experiments (fig. 4). Located about 45 miles east of Eugene, Oregon, this unique facility provides research opportunities available nowhere else in the United States. USGS and USFS scientists conduct experiments to improve the understanding of ground vibrations caused by debris flows and to refine automated debris-flow detection systems. The flume also provides an ideal environment for testing landslide controls that deflect, trap, or channelize debris flows. Experiments that assess how debris flows react to and act upon such controls can be used to guide and evaluate engineering designs.

The debris-flow flume is a reinforced concrete channel 310 feet long, 6.6 feet wide, and 4 feet deep that slopes 31 degrees, an angle typical of terrain where natural debris flows originate. Removable glass windows built into the side of the flume allow flows to be observed and photographed as they sweep past. A total of 18 data-collection ports in the floor of the flume permit measurements of forces due to particles sliding and colliding at the based of flows. Additional insight can be gained by using ultrasound imaging to "see" into the interior of flows and by deploying "smart rocks" containing miniature computers that record the rocks' accelerations as they move down the flume.

To create a debris flow, 20 cubic meters (about 40 tons) of saturated sediment are placed behind a steel gate at the head of the flume and then released. Alternatively, a sloping mass of sediment can be placed behind a retaining wall at the flume head and watered until slope failure occurs. The ensuing debris flow descends the flume and forms a deposit at the flume base. The flume design thus accommodates research on all stages of the debris-flow process, from initiation through deposition.

From Iverson, R.M., Costa, J.E., and LaHusen, R.G., 1982, Debris flow flume at H.J. Andrews Experimental Forest, Oregon: U.S.Geological Survey Open-File Report 92–483, 2 p.

Figure 4. The U.S. Geological Survey (USGS) debris-flow flume is located in H.J. Andrews Experimental Forest, Oregon. The flume was constructed to conduct controlled debris-flow experiments. Photograph courtesy of the USGS, taken September 13, 2001.

The National Landslide Hazards Mitigation Strategy

The National Landslide Hazards Mitigation Strategy described herein envisions a society that is fully aware of landslide hazards and routinely takes action to reduce both the risks and costs associated with those hazards. The strategy envisions bringing together relevant scientific, engineering, construction, planning, and policy capabilities of the Nation to eliminate losses from landslides and other ground-failure hazards nationwide.

The long-term mission of such a strategy is to provide and encourage the use of scientific information, maps, methodology, and guidance for emergency management, land-use planning, and development and implementation of public and private policy to reduce losses from landslides and other ground-failure hazards nationwide.

Reaching the Goal

The strategic plan described in this report has nine major elements, spanning a continuum from research to the formulation and implementation of policy and mitigation objectives. Implementation of such a strategy will demand a multiyear coordinated public and private effort. All levels of government and the private sector share responsibility for addressing these priorities and accomplishing the objectives. Some of the objectives consist of a single, discrete action; others encompass a series of interdependent actions to be taken over the first 10 years of implementation. Although the primary focus is on landslide hazards, the national strategy provides a framework for addressing other forms of ground failure as well.

The USGS has a role in each of the nine elements as a provider of landslide hazard information; however, the lead and participants in each element differ with the nature of the element.

Major Elements and Strategic Objectives

Element 1. Research

Research to develop a predictive understanding of landslide processes and triggering mechanisms will be led by the USGS. Hazard identification is a cornerstone of landslide hazard mitigation. Although many aspects of landslide hazards are well understood, a much more comprehensive understanding of landslide processes and mechanisms is required to truly advance our ability to predict the behavior of differing types of landslides. The following actions will increase the Nation's capability to forecast landslide hazards through enhanced research, the application of new technology, and an increased understanding of landslide processes, thresholds, and triggering mechanisms:

- Develop a national research agenda and a multiyear implementation plan based on the current state of scientific knowledge concerning landslide hazard processes, thresholds, and triggers and on the ability to predict landslide hazard behavior
- Develop improved, more realistic scientific models of ground deformation and slope failure processes and implement their use in predicting landslide hazards nationwide
- Develop dynamic landslide prediction systems capable of interactively displaying changing landslide hazards in both space and time in areas prone to different types of landslide hazards (for example, shallow debris flows during intense rain, deep-seated slides during months of wet weather, and rock avalanches during an earthquake)

Element 2. Hazard Mapping and Assessments

Efforts to delineate susceptible areas and different types of landslide hazards at a scale useful for planning and decisionmaking will be led by the USGS and State Geological Surveys. Landslide inventory and landslide susceptibility maps are critically needed in landslide-prone regions of the Nation. These maps must be sufficiently detailed to support mitigation action at the local level. To cope with the many uncertainties involved in landslide hazards, probabilistic methods are being developed to map and assess landslide hazards (see appendix 5 for more information about mapping and assessing landslide hazards). Risk assessments estimate the potential economic impact of landslide hazard events. Landslide inventory and susceptibility maps and other data are a critical first step and are prerequisite to producing probabilistic hazard maps and risk assessments, but these maps and data are not yet available for most areas of the United States. The following actions will provide the necessary maps and assessments and other information to officials and planners to reduce risk and losses:

- Develop and implement a plan for mapping and assessing landslide and other ground-failure hazards nationwide
- Develop an inventory of known landslide and other ground-failure hazards nationwide
- Develop and encourage the use of standards and guidelines for landslide hazard maps and assessments

Highlight 5— **Mapping Debris-Flow Hazards in Madison County, Virginia**

A major landslide event occurred in Madison County, Virginia, in the summer of 1995. During an intense storm on June 27th, 30 inches of rain fell in 16 hours. In mountainous areas, rain-saturated landslides known as debris flows were triggered by the hundreds, causing extensive devastation and one fatality.

Historical records tell us that destructive landslides and debris flows in the Appalachian Mountains occur when unusually heavy rain from hurricanes and intense storms soaks the ground, reducing the ability of steep slopes to resist the downslope pull of gravity. For example, during Hurricane Camille in 1969, such conditions generated debris flows in Nelson County, Virginia, 90 miles south of Madison County. The storm caused 150 deaths, mostly attributed to debris flows, and more than $100 million in property damage. Likewise, 72 hours of storms in Virginia and West Virginia during early November 1985 caused debris flows and flooding in the Potomac and Cheat River basins that were responsible for 70 deaths and $1.3 billion in damage to homes, businesses, roads, and farmlands.

Scientists from the U.S. Geological Survey have developed an inventory of landslides, debris flows, and flooding from the storm of June 27, 1995, by using aerial photography, field investigations, rainfall measurements from rain gages, and National Weather Service radar observations. This inventory and a new debris-flow hazard map (fig. 5) are being used to help understand the conditions that led to the floods and debris flows caused by the 1995 summer storms in Virginia and to suggest methods of mitigating the effects of such events in the future.

From Gori, P.L., and Burton, W.C., 1996, Debris-flow hazards in the Blue Ridge of Virginia: U.S. Geological Survey Fact Sheet FS–159–96, 4 p.

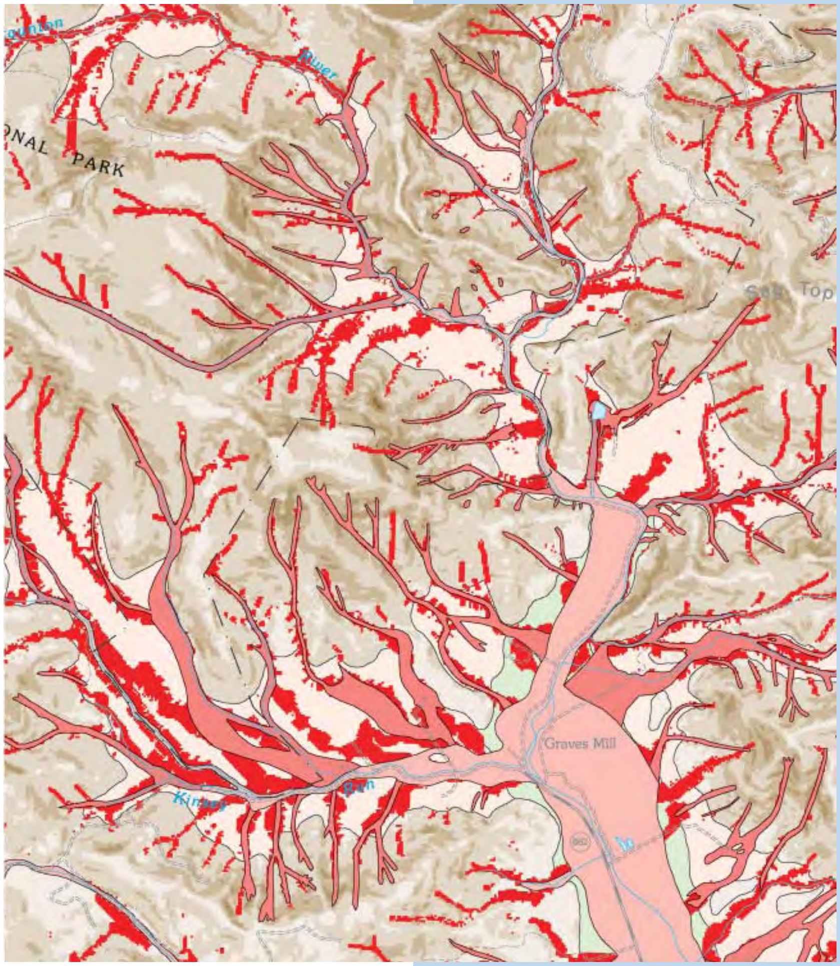

Figure 5. Portion of debris-flow hazard map, Madison County, Virginia. *From* Morgan, B.A., Wieczorek, G.F., and Campbell, R.H., 1999, Historical and potential debris-flow and flood hazard map of the area affected by the June 27, 1995, storm in Madison County, Virginia: U.S. Geological Survey Geologic Investigations Series Map I–2623–B, 1 sheet.

Element 3. Real-Time Monitoring

Studies to monitor active landslides that pose substantial risk will be led by the USGS. Monitoring active landslides serves the dual purpose of providing hazard warning in time to avoid or lessen losses, as well as supporting landslide research by providing new insights into landslide processes and triggering mechanisms. Collection of rare dynamic movement behavior data enables the testing of landslide velocity models and the development of improved predictive tools applicable to other slides. Development and application of real-time monitoring of active landslides using state-of-the-art research and telecommunications technologies are critically needed nationwide in cases of imminent risk. The following actions will provide the necessary warning and other information to officials and communities to avoid or reduce losses:

- Develop and implement a national landslide hazard monitoring and prediction capability
- Develop real-time monitoring and prediction capabilities on both site specific and regional scales, to assist Federal, State, and local emergency managers determine the nature of landslide hazards and the extent of ongoing risks
- Apply remote-sensing technologies such as Synthetic Aperture radar and laser altimetry for monitoring landslide movement nationwide
- Incorporate state-of-the-art techniques such as microseismicity and rainfall and pore-pressure monitoring with hydrologically based models of slope stability and global positioning systems (GPS)
- Integrate real-time monitoring capabilities with the National Weather Service’s NEXRAD capabilities in selected locations nationwide

Highlight 6—
Real-Time Monitoring of Active Landslides

Five landslides that threaten U.S. Highway 50 and nearby homes in Sierra Nevada, California, are being monitored by the U.S. Geological Survey (USGS) after heavy rains in January 1997 generated debris flows that blocked Highway 50. The cost of reopening the highway was $4.5 million, with indirect economic losses from closure of the highway amounting to an additional $50 million. To monitor the risk posed by landslides in this area, the USGS, in cooperation with local, State, and other Federal Agencies, provides continuous real-time monitoring of landslide activity using a system developed by the USGS for monitoring active volcanoes in remote areas (fig. 6).

This system measures ground movement and ground-water pressures every second. Slope movement is recorded by instruments that detect stretching and shortening of the ground (fig. 7). Ground vibrations caused by slide movement are monitored by geophones buried within the slide. Ground-water conditions within the slides are monitored by sensors, and rain gauges record precipitation. Under normal conditions, data are transmitted to USGS computers every 10 minutes, but if strong ground vibrations caused by massive landslide movement are detected, data are transmitted immediately (fig. 8).

The USGS operates other remote real-time landslide monitoring sites. Near Seattle, Washington, a real-time system monitors a slide threatening a major railway, and in Rio Nido, California, another system monitors a large landslide threatening more than 140 homes. Remote monitoring also can record the effects of wildfire in destabilizing slopes.

From Reid, M.E., LaHusen, R.G., and Ellis, W.L., 1999, Real-time monitoring of active landslides: U.S. Geological Survey Fact Sheet FS–91–99, 2 p.

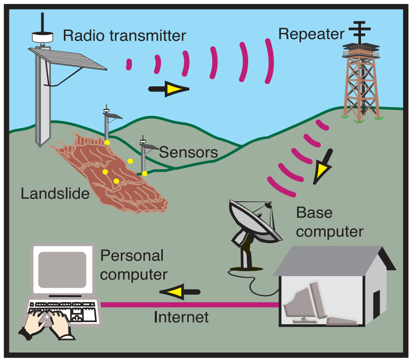

Figure 6. Network for transmission of real-time landslide data.

Figure 7. Measuring landslide movement. Photograph by Richard LaHusen, U.S. Geological Survey.

Figure 8. Testing a solar-powered radio telemetry system for remote transmission of real-time landslide data. Photograph by Mark Reid, U.S. Geological Survey.

Element 4. Loss Assessment

A project compiling and evaluating information on the economic impacts of landslide hazards will be led by FEMA and the insurance industry. Although losses from landslides and other natural hazards are frequent and widespread, these losses are not consistently compiled and tracked in the United States. Following a landslide or other natural hazard event, a variety of different agencies and organizations may provide damage estimates, but these estimates usually vary widely, cover a range of different costs, and change through time. The National Research Council concluded in their 1999 report "The Impact of Natural Disasters—A Framework for Loss Estimation" that there is no widely accepted framework for estimating the losses from natural disasters, including landslide and other ground-failure hazards. This lack of information makes it difficult to set policies for coping with these hazards and difficult to gage the cost-effectiveness of policy decisions and effectiveness of mitigation measures. Loss data are critically needed to help government agencies identify trends and track progress in reducing losses from landslides. The following actions will provide a framework for compiling and assessing a comprehensive data base of losses from landslides and other ground -failure hazards, which will help guide research, mapping, and mitigation activities nationwide:

- Assess the current status of data on losses from landslides and other ground failures nationwide, including the types and extent of losses to public and private property, infrastructure, and natural and cultural resources
- Establish and implement a national strategy for compilation, maintenance, and evaluation of data on the economic and environmental impacts of landslide and other ground-failure hazards nationwide to help guide mitigation activities and track progress

Highlight 7—
Inventory of Slope Failures in Oregon for Three 1996–97 Storm Events

Three significant Pacific Northwest storm events in February 1996, November 1996, and late December 1996 and early January 1997 initiated widespread slope failures throughout Oregon. Each of these storms was declared a "Major Presidential Disaster Declaration," and damages to natural resources and infrastructure were extreme. In the Portland metropolitan region, Oregon's largest city, more than 700 slope failures were associated with the heavy rains in 1996, with 17 houses completely destroyed and 64 partially condemned. An estimate of statewide public and private damages incurred from the February 1996 event alone is $280 million.

To better characterize the distribution and magnitude of the slope failures associated with the three storms, the Federal Emergency Management Agency provided funding for the consolidation of a landslide inventory (fig. 9). The Oregon Department of Geology and Mineral Industries led the consolidation effort and utilized various methods to contact potential data sources, inform them of the existence of the study, and request their participation. This inventory will help lead to a greater understanding of regional landslide issues and assist government and community agencies in devising means to minimize the threat to public health and property that landslides pose.

Over 9,000 landslide locations were incorporated into the inventory, with varying amounts of information reported for each. Many other slides were not observed or recorded, and it is estimated that two to three times this many landslides occurred during the time period. As shown on the landslide inventory map, the vast majority (98 percent) of the entries are in the western portion of the State. Most of these slides occurred in the Oregon Coast Range and Cascade province, with fewer in the Willamette Valley and Klamath Mountains.

From Hofmeister, R.J., 2000, Database of slope failures in Oregon for three 1996/97 storm events: Oregon Department of Geology and Mineral Industries.

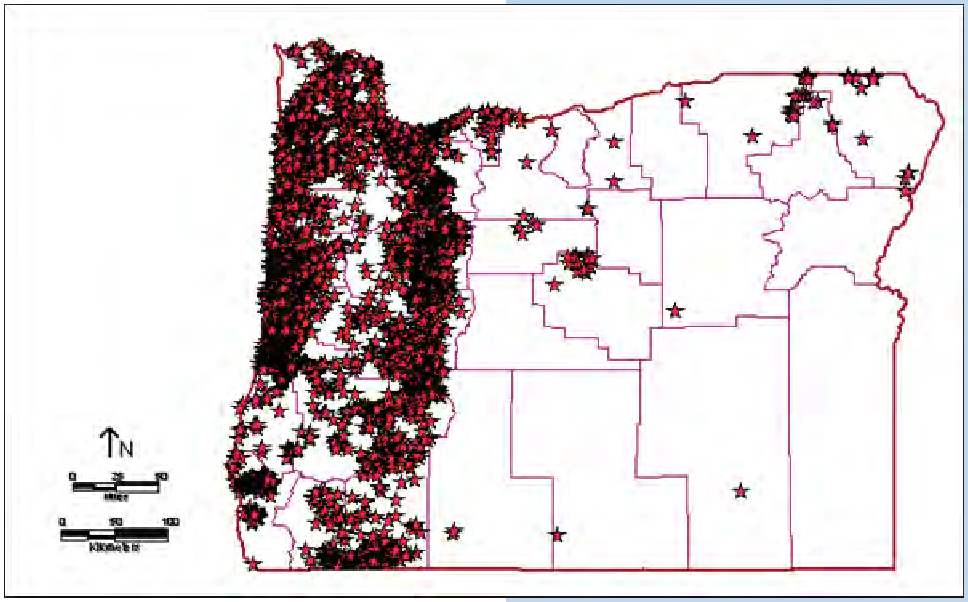

Figure 9. Landslide inventory for three 1996–97 storm events in Oregon.

Element 5. Information Collection, Interpretation, Dissemination, and Archiving

The effort to establish an effective system for information transfer will be led by the USGS and State Geological Surveys. Collecting and disseminating landslide hazards information to Federal, State, and local government agencies; nongovernmental organizations; planners; policymakers; and private citizens in a form useful for planning and decisionmaking are critically important to an effective mitigation program. Although landslide hazards have been studied for decades, a systematic effort to collect and distribute scientific and technical information is in its relative infancy. The USGS National Landslide Information Center is a prototype system that can be enhanced and extended into a robust nationwide system for the collection, interpretation, and dissemination of landslide hazard maps, assessments, and other scientific and landslide hazard technical information. The following objectives will make landslide hazard information accessible to scientists, officials, decisionmakers, and the public to assist research, planning, policy, and mitigation activities:

- Evaluate and use state-of-the-art technologies and methodologies for the dissemination of technical information, research results, maps, and real-time warnings of potential landslide activity
- Develop and implement a national strategy for the systematic collection, interpretation, archiving, and distribution of this information

Highlight 8—
Warning of Potential Landslides

An experimental monitoring and warning system was developed and operated jointly by the U.S. Geological Survey (USGS) and the National Weather Service (NWS) from the 1980s to 1995 in the San Francisco Bay region (fig. 10). The system used (1) NWS protocols and outlets for issuing warnings and (2) regional networks of NWS and USGS rain gages and soil-moisture instruments to track rainfall and soil-moisture conditions. Rainfall thresholds for triggering landslides were determined on the basis of observed relationships between rainfall intensity and duration and the occurrence of landslides. When real-time data and high precision forecasting by the NWS indicated that the rainfall threshold for landslides had or would soon be reached, USGS scientists informed the NWS to issue a warning through normal media channels. The media, government officials, and the general public in the bay area came to rely on these warnings and took specific actions such as evacuating neighborhoods at particular risk.

Under the National Landslide Hazards Mitigation Strategy, next-generation landslide warning systems will be implemented in landslide-prone regions nationwide. Precipitation, soil moisture, and pore-pressure data will telemetered in real time to network centers for processing and analysis. These measurements will help define the precipitation thresholds and supplement the NWS NEXRAD (Next Generation Radar) network and other precipitation data and forecasts provided by the NWS or local agencies. Warnings of potential landslide activity that might be triggered by storms or extended rainy periods will be issued in cooperation with the NWS and Federal and State emergency management agencies.

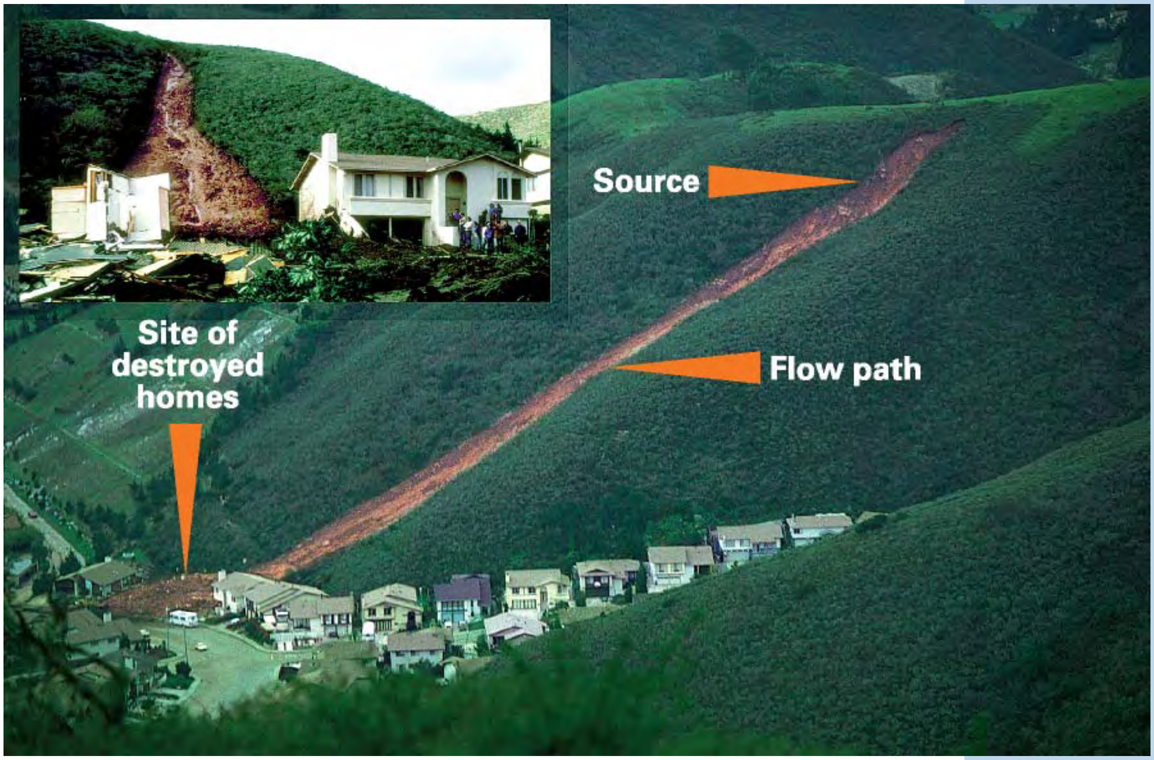

Figure 10. Debris flow from a steep hillslope in Pacifica, California, about 10 miles south of San Francisco, where three children were killed and two homes destroyed on January 4, 1982. Inset, View of destroyed homes from the street. Photograph by Gerald Wieczorek, U.S. Geological Survey. *From* U.S. Geological Survey, 1995, Debris-flow hazards in the San Francisco Bay region: U.S. Geological Survey Fact Sheet FS–112–95, 2 p. Available on the web at http://greenwood.cr.usgs.gov/pub/fact-sheets/fs-0112-95/.

Element 6. Guidelines and Training

Efforts to develop guidelines and training for scientists, engineers, and decisionmakers will be led by the USGS and professional societies. The study of landslide hazards is an area of active research and technological application, and there is a critical need for guidelines and training for scientists and engineers in the development of landslide maps and assessments. Hazard assessments involve assumptions and calculations about the magnitude and return frequency in specific geographic settings. Risk assessments involve assumptions about the potential physical and economic impacts of landslide hazard events. The development and presentation of the results in terms that are useful to citizens and decisionmakers are critically important to effective mitigation. Likewise, development of guidelines and training for planners and other decisionmakers in the use of these maps and assessments are important to encouraging its appropriate use by the user community. The following are high priority objectives related to guidelines and training:

- Develop and implement guidelines and training for scientists and geotechnical engineers in the use of landslide hazard and other technical information for mapping and assessing landslide hazards
- Develop and implement guidelines and training for scientists and geotechnical engineers for responding to landslide disasters and providing needed scientific and technical information for response and recovery efforts
- Develop and implement guidelines and training for planners and decisionmakers in the use of landslide hazard maps, assessments, and other technical information for planning, preparedness, and mitigation

Element 7. Public Awareness and Education

Efforts to develop information and education programs for the user community will be led by FEMA and the USGS. Before individuals and communities can reduce their risk from landslide hazards, they need to know the nature of the threat, its potential impact on them and their community, their options for reducing the risk or impact, and methods for carrying out specific mitigation measures. Achieving widespread public awareness of landslide hazards will enable communities and individuals to make informed decisions on where to live, purchase property, or locate a business. Local decisionmakers will know where to permit construction of residences, business, and critical facilities to reduce potential damage from landslide hazards. The following actions will raise public awareness of landslide hazards and encourage landslide hazard preparedness and mitigation activities nationwide, tailored to local needs:

- Develop public awareness, training, and education programs involving land-use planning, design, landslide hazard curriculums, landslide hazard safety programs, and community risk reduction
- Evaluate the effectiveness of different methods, messages, and curriculums in the context of local needs
- Disseminate landslide-hazard-related curriculums and training modules to community organizations, universities, and professional societies and associations

Highlight 9—
Alerting the Public to the Hazards of Mount Rainier

Mount Rainier in Washington State is an active volcano that is currently at rest between eruptions. Its next eruption may produce volcanic ash, lava flows, or pyroclastic flows (fig. 11). Pyroclastic flows are hot avalanches of lava fragments and gas formed by volcanic eruptions. Pyroclastic flows can rapidly melt snow and ice, and the resulting meltwater torrent may produce lahars (the widely used Indonesian word for volcanic mudflows and debris flows) that travel down valleys beyond the base of the volcano. Lahars may also occur during noneruptive times when a section of the volcano collapses.

Lahars look and behave like rapidly flowing concrete, and their impact can destroy most manmade structures. Historically at Mount Rainier, they have traveled 45–50 miles per hour in thicknesses of 100 feet or more in confined valleys, slowing and thinning as they flowed into wider valleys, most of which are populated. At Mount Rainier, lahars pose a greater risk than other volcanic hazards, such as lava and poisonous gases.

The likely courses of lahars are the river valleys that drain Mount Rainier. Four of the five major river systems flow westward into suburban areas of Pierce County. The U.S. Geological Survey mapped the likely flow pathways and has joined with local, county, and State agencies to develop a Mount Rainier hazards plan that will address such issues as emergency response operations and strategies for expanded public awareness and mitigation.

From Scott, K.M., Wolfe, E.W., and Driedger, C.L., 1998, Mount Rainier; living with perilous beauty: U.S. Geological Survey Fact Sheet FS–065–97, 4 p. *and* Hoblitt, R.P., Walder, J.S., Driedger, C.L., Scott, K.M., Pringle, P.T., and Vallance, J.W., 1998 (rev.), Volcano hazards from Mount Rainier, Washington: U.S. Geological Survey Open-File Report 98–428, 11 p., 2 oversize sheets.

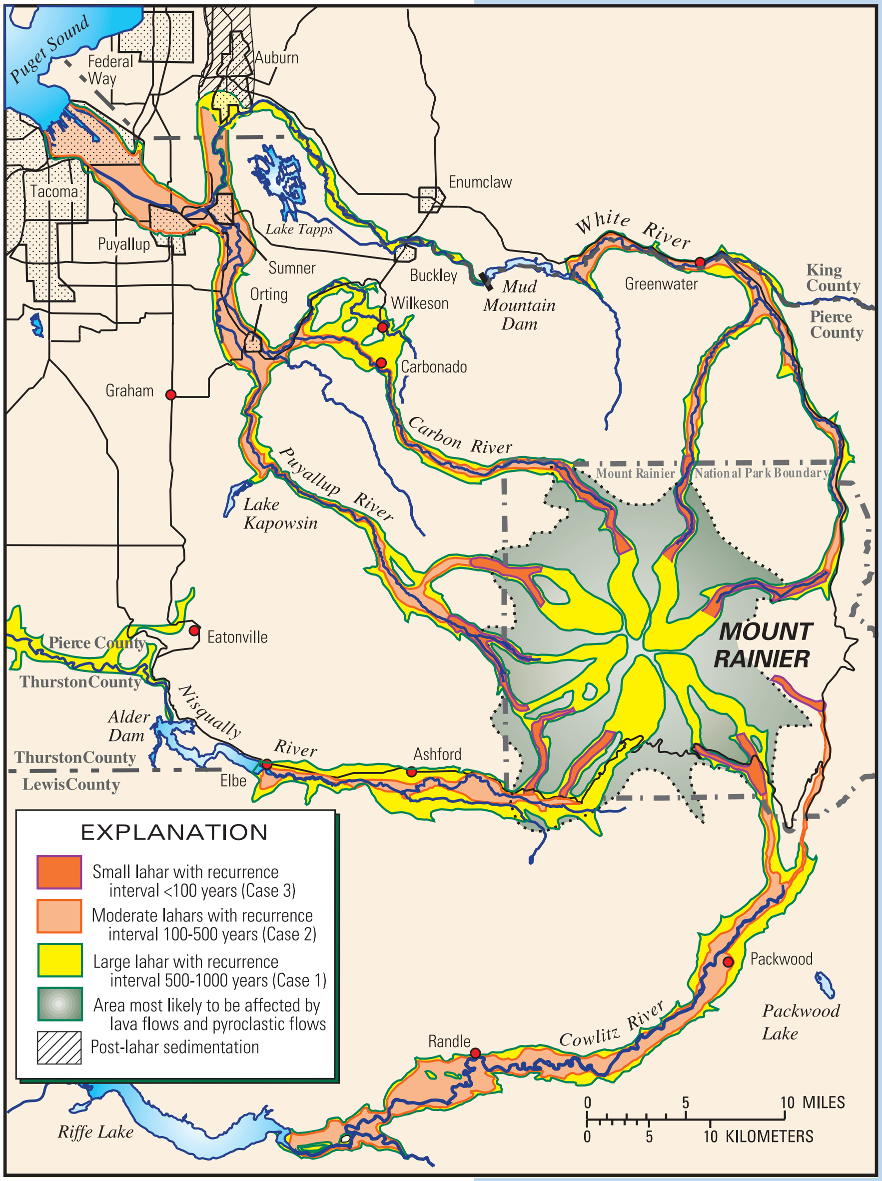

Figure 11. Hazard zones from lahars, lava flows, and pyroclastic flows from Mount Rainier. *From* Scott, K.M., Wolfe, E.W., and Driedger, C.L., 1998, Mount Rainier; living with perilous beauty: U.S. Geological Survey Fact Sheet FS–065–97, 4 p.

Element 8. Implementation of Loss Reduction Measures

Efforts to encourage mitigation action will be led by FEMA, State departments of emergency services, and professional societies. A successful strategy for reducing landslide losses must also include a mitigation component. Mitigation actions generally fall to State and local governments, businesses, and individuals. As a result, societal attitudes and perceptions can present formidable obstacles to landslide hazards reduction. Few communities have considered the full range of mitigation options despite their feasibility and cost effectiveness. Mitigation measures at the local level include a range of tools and techniques, such as land-use planning, regulation of development, engineering controls, building codes, assessment districts, emergency planning and warning, and private financial and insurance incentives and disincentives. The following actions will facilitate and encourage implementation of appropriate and effective mitigation measures that are tailored to local needs:

- Evaluate impediments to effective planning and controls on development and identify approaches for removing those impediments.
- Develop an education program for State and local elected and appointed officials that sensitizes them to the risk and costs of landslide hazards and encourages them to develop legislation and policies that support effective landslide hazard mitigation
- Develop and disseminate prototype incentives and disincentives for encouraging landslide mitigation to government agencies, the private sector, and academia
- Evaluate engineering and construction approaches to mitigate landslide hazards and develop a national plan for research to improve these techniques
- Encourage implementation of successful landslide mitigation technologies

Highlight 10—
Cincinnati, Ohio—A Leader in Landslide Loss Reduction Measures

Landslides are a significant problem in several areas of Ohio, and Cincinnati has one of the highest per capita costs due to landslide damage of any city in the United States. Landslides have been known to occur in the Cincinnati area in southwestern Ohio and the adjoining States of Kentucky and Indiana since before the 1850s, but the damage caused by landslides has become increasingly expensive as urban development encroaches more and more on the area's hillsides. The city of Cincinnati spent an average of $550,000 per year on emergency street repairs for damage due to landslides between 1983 and 1987 (fig. 12).

In 1974, the Cincinnati City Council passed an excavation and fill ordinance to help reduce landslide damage in areas of new construction. In 1989, Cincinnati created a geotechnical office within its Department of Public Works. The office, which is staffed by a geotechnical engineer, an engineering geologist, and two technicians, carries out a mitigation program. Since 1989, members of the geotechnical staff have worked in several ways to reduce landslide damage in the city; their work includes engineering geologic mapping of selected parts of the city, inspecting retaining walls that affect public right-of-way, reviewing proposed construction in hillside areas, inspecting and arranging for repair of landslide areas that affect city property, and compiling geologic and geotechnical data on landslide areas within the city. In 1990, Hamilton County also adopted an excavation and fill ordinance to help reduce the damage due to landslides in areas of new construction.

From Hansen, M.C., 1995, Geofacts: Ohio Department of Natural Resources, no. 8 *and* Baum, R.L., and Johnson, A.M., 1996, Overview of landslide problems, research, and mitigation, Cincinnati, Ohio, area: U.S. Geological Survey Bulletin 2059–A, p. A1–A33.

Figure 12. Earthflow material being removed by a highway crew along the Columbia Parkway, Cincinnati, Ohio. Hamilton County, in the metropolitan Cincinnati area, experienced an average annual economic loss of $5.80 per person (1975 dollars) between 1973 and 1978, the highest calculated per capita loss of any municipality in the United States. Photograph courtesy of the U.S. Geological Survey.

Element 9. Emergency Preparedness, Response, and Recovery

Efforts to develop resilient communities will be led by FEMA and State departments of emergency services. Despite improved landslide hazard mitigation, disasters will occur. For this reason, governments at all levels, the private sector, and the public will need to be able to adequately prepare for, respond to, and recover from disasters involving landslides. Governments will need to better plan for landslide emergencies. Scientists, engineers, and emergency response professionals will need to be trained in the best practices to employ during a response, and public officials responsible for recovery from disasters will need to be informed of options that will reduce future landslide losses. Incorporating the following actions in a national landslide mitigation strategy will improve the Nation's ability to respond to and recover from landslide disasters:

- Provide training for Federal, State, and local emergency managers on landslide hazards preparedness, response, and recovery
- Develop a coordinated landslide rapid response capability to assist local, State, and Federal emergency managers in determining the nature of landslide hazards and the extent of ongoing risks
- Provide dedicated landslide expertise and equipment required for rapid emergency deployment of real-time data to emergency managers, as well as the ability to successfully transfer monitoring technology to other agencies

Highlight 11—
Daly City—The Human Cost of Landslides

Active landslides pose an increasing problem to older communities. An example of this dilemma came to a head in April 2000, when 21 late-1950s era homes in Daly City, California, were condemned because of continued landsliding along Westline Drive. The homes were deemed permanently uninhabitable, and the city had no choice but to remove their inhabitants from imminent danger. By May, all residents had moved.

The Westline Drive landslide first came to the attention of Daly City residents in 1966, when sliding forced the removal of homes from a subdivision developed just 7 years earlier. One more home was removed in 1980. The movement lessened until the El Niño winter of 1997–98, one of the wettest rainy seasons on record, caused the landslide to reactivate (fig. 13). As a result, Westline Drive dropped as much as 4 feet in some areas.

The decision by the city to condemn the houses was in reaction to the local gas utility's decision to shut off gas service in February to the affected area of Westline drive after finding numerous irreparable leaks. The utility feared that pipe ruptures would cause an explosion. In addition, the city closed off the street to traffic, including garbage and emergency vehicles, after discovering a 10-foot-square cavity beneath the pavement.

Assisting the homeowners was a challenge because no insurance was available. The Federal Emergency Management Agency offered to buy the homes, but funds covered only part of the previous value of the homes. The Federal Small Business Administration offered mortgage loans at 4 percent, but only for a reduced value of the homes, and the homeowners had to pay off their existing mortgages. Daly City and San Mateo County planned to supplement the Federal Government's $6.5 million offer of assistance with housing funds totaling $1 million. Daly City planned to take over the deeds from the homeowners and turn the land into open space.

From San Francisco Chronicle, March 30 and May 2, 2000, Angelica Pence, staff writer, and Russell Graymer, U.S. Geological Survey.

Figure 13. Gully retreat threatening evacuated houses in Daly City, a suburb of San Francisco, California, following the storm of February 2–3, 1998. Landslide and mudslide activity was extensively reported in the news media following heavy rains on February 2–3, 1998. A number of scattered, slow-moving landslides had been active over the weeks prior to the storm in San Francisco, Oakland, and elsewhere in the San Francisco Bay region. As most of the area experienced about 200 percent of normal rainfall in the winter of 1998, these landslides were probably related more to the wet winter and less to the effects of this particular storm. However, based on limited ground reconnaissance, scattered slope movements directly related to the storm did occur. Debris flows directly triggered by the storm affected a number of homes and properties. *From* U.S. Geological Survey web site http://landslides.usgs.gov/html_files/landslides/reconrpt.html, 1998, accessed July 29, 2002. Photograph by Steve Ellen, U.S. Geological Survey.

Action Items for a National Strategy for Reducing Losses from Landslides

Landslide hazard mitigation necessitates interactive collaboration among academia, industry, government, and the private sector. The following key aspects of a National Landslide Mitigation Strategy will allow for rapid and significant progress toward a sustained mitigation of landslide hazards nationwide:

Key Steps for Implementation

- Conduct Federal-State and public-private forums to establish regional priorities for research, mapping, monitoring, forecasting, and mitigating landslide hazards
- Establish new and enhance existing programs to fund research, mapping, monitoring, and mitigation activities nationwide
- Develop Federal-State and public-private programs to delineate landslide prone areas, to forecast the potential for landslides, and to mitigate losses
- Establish and enhance Federal-State and public-private partnerships to leverage and maximize relevant resources and expertise

Management Plan

Durable and effective solutions to the Nation's ground-failure-hazard problems will require a continuing dialog among and concerted action by all sectors of our society. An effective National Landslide Hazards Mitigation Strategy will require a combination of purposeful management to ensure coordination and consortium-type decisionmaking to accommodate the multi-jurisdictional, cooperative nature of the program. An effective management plan will include the following:

- Establish coordination of the National Landslide Hazards Mitigation Strategy under the leadership of the USGS, using the bureau's expertise and experience in landslide hazards research, monitoring, mapping and data collection, analysis, archiving, and dissemination
- Establish working groups with representatives of Federal, State, and local governments, academia, and private industry to help coordinate and guide the National Landslide Hazards Mitigation Strategy
- Establish Federal-State public-private cooperative programs to fund and encourage landslide hazard research, mapping, assessment, and mitigation efforts nationwide

New and Enhanced Roles and Partnerships

Many Federal, State, and local agencies; academia; and private companies are involved in landslide research and mitigation in the United States (see appendixes 6 and 7 for more information about Federal, State, and local programs). A National Landslide Hazards Mitigation Strategy offers new opportunities for mutually advantageous partnerships relating to hazard assessments, monitoring, and emergency response and recovery.

The national strategy enhances the ability of Federal, State and local agencies to partner effectively with the academic and the private sectors and to leverage shared resources. Table 1 outlines the complementary and supportive roles and opportunities for new partnerships for each participant in the National Landslide Hazards Mitigation Strategy.

Table 1. New roles and partnership opportunities under the National Landslide Hazards Mitigation Strategy.

<table>
<tr><th rowspan="2">Element</th><th rowspan="2">Current status</th><th colspan="5">New roles and partnership opportunities</th></tr>
<tr><th>Federal</th><th>State</th><th>Local</th><th>Private</th><th>Academic</th></tr>
<tr><td rowspan="3">1. Research.—
Developing a predictive understanding of landslide processes and triggering mechanisms</td><td rowspan="3">A much more comprehensive understanding of landslide processes and mechanisms is required to advance our ability to predict the behavior of different types of landslides.</td><td colspan="2">Coordinate research priorities</td><td colspan="3"></td></tr>
<tr><td colspan="5">Conduct research</td></tr>
<tr><td colspan="4">Use results of research in policy, planning, and mitigation decisions</td><td></td></tr>
<tr><td rowspan="4">2. Hazard Mapping and Assessments.—
Delineating susceptible areas and different types of landslide hazards at a scale useful for planning and decisionmaking</td><td rowspan="4">Landslide inventory and landslide susceptibility maps are critically needed in many landslide-prone regions of the Nation. In general, there are no standards for mapping and assessments.</td><td>Map landslides on Federal lands</td><td colspan="4"></td></tr>
<tr><td colspan="2">Establish mapping and assessment standards</td><td colspan="3"></td></tr>
<tr><td colspan="5">Map and assess landslide hazards</td></tr>
<tr><td colspan="5">Use landslide hazard maps and assessments in planning, preparedness, and mitigation</td></tr>
<tr><td rowspan="2">3. Real-Time Monitoring.—
Monitoring active landslides that pose substantial risk</td><td rowspan="2">Real-time monitoring of active landslides is critically needed nationwide.</td><td colspan="5">Improve real-time monitoring capabilities</td></tr>
<tr><td colspan="4">Monitor landslides and establish landslide warning systems</td><td></td></tr>
<tr><td rowspan="2">4. Loss Assessment.—
Compiling and evaluating information on the economic and environmental impacts of landslide hazards.</td><td rowspan="2">Losses are not consistently compiled and tracked in the United States.</td><td>Establish and implement a national strategy for compilation, maintenance, and evaluation of data</td><td colspan="4"></td></tr>
<tr><td colspan="5">Compile and share records of losses</td></tr>
<tr><td>5. Information Collection, Interpretation, Dissemination, and Archiving.—
Establishing an effective system for information transfer</td><td>There is no systematic nationwide collection or distribution of landslide hazards information.</td><td colspan="2">Develop robust landslide hazards information clearinghouse system for the systematic collection, interpretation, archiving, and distribution of scientific and technical information, data bases, and maps</td><td colspan="2">Collect and distribute needed information to decisionmakers</td><td>Develop and share information</td></tr>
</table>

Table 1. New roles and partnership opportunities under the National Landslide Hazards Mitigation Strategy.—Continued

<table>
<tr><th rowspan="2">Element</th><th rowspan="2">Current status</th><th colspan="5">New roles and partnership opportunities</th></tr>
<tr><th>Federal</th><th>State</th><th>Local</th><th>Private</th><th>Academic</th></tr>
<tr><td rowspan="2">6. Guidelines and Training.—
Developing guidelines and training for scientists, engineers, and decisionmakers</td><td rowspan="2">There is a critical need for guidelines and training for scientists, engineers, planners, and decisionmakers.</td><td colspan="5">Develop and implement guidelines and training curriculums</td></tr>
<tr><td colspan="5">Participate in training programs</td></tr>
<tr><td>7. Public Awareness and Education.—
Developing information and education programs for the user community</td><td>There is little public awareness and understanding of landslide hazards, impacts on communities, or options for reducing risk.</td><td colspan="5">Develop and implement public awareness and education programs, involving land-use planning, design, and landslide hazard curriculums; landslide hazard safety and community risk reduction</td></tr>
<tr><td rowspan="2">8. Implementation of Loss Reduction Measures.—
Encouraging mitigation action</td><td rowspan="2">Mitigation necessarily occurs at the local level; therefore, implementation of loss reduction measures varies from community to community.</td><td colspan="2" rowspan="2">Develop and encourage policies that support landslide hazard mitigation
Develop financial incentives and disincentives that support landslide hazard mitigation
Develop and encourage engineering and construction approaches to mitigate landslide hazards</td><td colspan="3">Adopt and implement policies and practices that support landslide hazards mitigation</td></tr>
<tr><td></td><td colspan="2">Serve as consultants and advisors</td></tr>
<tr><td rowspan="2">9. Emergency Preparedness, Response, and Recovery.—
Developing resilient communities</td><td rowspan="2">Federal, State, and local governments; the private sector; and the public need to be able to adequately prepare, respond to, and recover from landslide emergencies.</td><td colspan="2" rowspan="2">Provide training for Federal, State, and local emergency managers
Develop a coordinated landslide rapid response capability, including landslide hazards expertise and equipment required for rapid emergency deployment of real-time data to emergency managers</td><td>Participate in training</td><td colspan="2">Provide expertise during emergencies</td></tr>
<tr><td colspan="2">Effectively respond to landslide emergencies

Implement policies that reduce future landslide losses</td><td></td></tr>
</table>

Funding for the USGS to Implement a National Strategy for Reducing Losses from Landslides

Implementation of the National Landslide Hazards Mitigation Strategy within the USGS Landslide Hazards Program (LHP) will involve four principal tasks—

- Expansion of work performed by scientists in the Landslide Hazards Program
- Establishment of new Cooperative Landslide Hazard Assessment and Mapping Program
- Establishment of a new Cooperative Federal Land Management Landslide Hazards Program
- Establishment of new partnerships for the Landslide Hazard Loss Reduction Program

The USGS Landslide Hazard Program is currently funded for $2.26 million in FY 2002. The changes above will require expansion of and additional funding for the LHP.

Expansion of the Work Performed by Scientists in the Landslide Hazards Program

Expanding efforts by USGS scientists in the areas of research, hazard assessment, monitoring, public information, and response will be necessary to meet the challenges of the national strategy. The Landslide Hazards Program will also require additional funding to meet new responsibilities to coordinate activities within the Federal Government to fully implement the strategy. Approximately $8 million in new funding will be required to support the following:

- Additional research on landslide processes and triggering mechanisms (element 1) ($1.5 million)
- Additional hazard maps and assessments of landslide-susceptible areas, including developing standards and guidelines (element 2) ($2 million)
- Additional monitoring of active landslides and improvement of state-of-the-art research and telecommunications technology (element 3) ($2 million)
- Improved information collection, interpretation, dissemination, and technology transfer, including public awareness programs and education (elements 5 and 7) ($1 million)
- Expanded emergency response and recovery capability and activities (element 9) ($1 million)
- Coordination of National Landslide Hazard Mitigation Strategy ($0.5 million)

Establishment of a New Cooperative Landslide Hazard Assessment and Mapping Program

A new cooperative program will be established to encourage the understanding and mitigation of landslide and other ground-failure hazards by States, Territories, counties, and other local jurisdictions. The program will be administered by the USGS Landslide Hazards Program. The primary goal of this cooperative program will be to reduce hazard losses by increasing the availability of assessments and maps of landslide- and other ground-failure-prone areas in the United States. This program will address all elements of the national strategy, with a primary focus on element 2, landslide hazard mapping and assessments. The USGS will provide guidance to encourage standardized assessment and map products that will be available digitally.

Priorities will be determined annually in consultation with State and Territory representatives. Grants to States and Territories will be awarded competitively. States and Territories will determine priorities and the size of grants to be distributed to their local jurisdictions in consultation with Statewide and Territorywide advisory committees.

Approximately $8.0 million will be required to support competitive grants to the States, Territories, and local jurisdictions each year. Each grant will be matched by a 30 percent State or Territory contribution to encourage the development and use of landslide information in planning and mitigation actions at the State and local levels. It is anticipated that all States and Territories will participate in such a program and that grants will average $150,000 per State or Territory.

Establishment of a New Cooperative Federal Land Management Landslide Hazards Program

A new program, administered by the USGS Landslide Hazards Program, will be established to increase and encourage the understanding and mitigation of landslide hazards on Federal lands, including assessment and mapping of landslides, land-use planning and facility siting, emergency management, and public education.

The goal of such a program will be to reduce losses from landslide and other ground-failure hazards through more informed and, therefore, better stewardship of Federal lands under the jurisdiction of the National Park Service, the Bureau of Land Management, the Bureau of Reclamation, the Bureau of Indian Affairs, and the U.S. Forest Service. The new program will address all elements of the national strategy, with a primary focus on landslide hazard mapping, assessments, and monitoring (elements 2 and 3).

Priorities for scientific and technical assistance for Federal land management agencies will be determined annually in consultation with representatives of Federal land management agencies. Approximately $2.0 million will be required for scientific and technical assistance for Federal land management agencies. It is anticipated that the program will support approximately 20 agreements, averaging $100,000 each. Most of these funds will be used to support hazard assessments and procure monitoring equipment, with USGS staff providing technical assistance

Establishment of New Partnerships for Landslide Hazard Loss Reduction Program

A new competitive external grants program, administered by the USGS Landslide Hazards Program, will be established for research and implementation efforts. The program will foster partnerships with universities, private consulting firms, professional associations, Federally recognized Indian Tribal Governments, States and Territories, and local agencies. This program will address all elements of the strategy, with a primary focus on landslide hazard research and development and application of mitigation measures (elements 1, 2, and 8).

Priorities for research and application of research will be determined annually in consultation with Federal, State, Territory, local, and private representatives. Approximately $2.0 million will be required for cooperative agreements with universities, private consulting firms, professional associations, Federally recognized Indian Tribal Governments, States and Territories, and local agencies to support research and innovative application of research. It is anticipated that the program will support approximately 25 agreements, averaging $80,000 each.

Funding Summary

Total new funding to support implementation of a National Landslide Hazard Mitigation Strategy is estimated to be $20 million annually, as follows:

- Expansion of the research, assessment, monitoring, public information, and response efforts by USGS scientists ($8 million annually)
- Establishment of a Cooperative Landslide Hazard Assessment and Mapping Program to increase the efforts of State and local governments to map and assess landslide hazards within their jurisdictions through competitive grants ($8 million annually, to be augmented with 30 percent matching funds by States and local jurisdictions)
- Establishment of a Cooperative Federal Land Management Landslide Hazard Program to increase the capability of the National Park Service, U.S. Forest Service, Bureau of Land Management, and other such organizations to address landslide hazards under their jurisdictions ($2 million annually for work performed by USGS scientists on public lands)
- Establishment of a Partnerships for Landslide Hazard Loss Reduction Program to support research and implementation efforts by universities, local governments, and the private sector through competitive grants ($2 million annually)

Major Accomplishments and Products

Full implementation of the National Landslide Hazards Mitigation Strategy will result in a number of major accomplishments and products over the first 10 years of the program, including the following:

- Reduced losses from landslides
- Reduced risk from future landslides
- Greater public awareness of landslide hazards and options for mitigating losses
- Improved technology for landslide mitigation
- Assessments and maps of landslide susceptibility in landslide-prone areas
- Assessments and maps of other ground-failure hazards in susceptible areas
- Assessments and maps of landslide and ground-failure susceptibility on Federal Lands
- Policies to encourage landslide mitigation by government, communities, and the private sector
- Robust national landslide hazards information clearinghouse system
- Data bases of economic and environmental losses from landslides and other forms of ground failures nationwide
- Guidelines and training materials for scientists, engineers, planners, decisionmakers
- Curriculums and training materials for public awareness of landslide hazards
- Real-time monitoring of critically hazardous active landslides nationwide
- Coordinated landslide emergency response capability nationwide

Progress in implementing the National Landslides Hazards Mitigation Strategy will be monitored by working groups established to coordinate and guide the strategy. These groups will include representatives of Federal, State, and local governments and the private sector. Specific performance goals for the strategy, including accomplishments and products, will come from a comprehensive review of national needs and priorities and will result in specific plans and schedules. In addition, progress in reducing losses will be monitored as part of element 4— compilation and evaluation of losses from landslide hazards.

Acknowledgments

This report is based on an early draft by Randall Updike of the USGS and on the ideas and suggestions from landslide hazard experts and others who attended five stakeholder meetings. The report benefited from contributions from and reviews by numerous USGS scientists and other Federal and State agency representatives. The authors would especially like to thank the American Association of State Geologists for their thoughtful input and review of the report.

Appendix 1. Previous Reports and Sources of Landslide Hazards Information

The proposed National Landslide Hazards Mitigation Strategy incorporates many ideas and recommendations of previous studies and reports. The following studies and reports should be referred to for more in-depth discussions of and insights into landslide hazard mitigation and research needs.

U.S. Geological Survey Open-File Report 81–987, Goals, Strategies, Priorities and Tasks of a National Landslide Hazard Loss Reduction Program (USGS, 1981), sets forth goals and tasks for landslide studies, evaluating and mapping a hazard, disseminating information, and evaluating the use of the information.

U.S. Geological Survey Circular 880, Goals and Tasks of the Landslide Part of a Ground-Failure Hazards Reduction Program (USGS, 1982), describes a national program.

U.S. Geological Survey Open-File Report 85–276, Feasibility of a Nationwide Program for the Identification and Delineation of Hazards from Mud Flows and Other Landslides (Campbell and others, 1985), identifies the need for a national program.

Reducing Losses from Landsliding in the United States (Committee on Ground Failure Hazards, National Research Council, 1985, National Academy Press) recommends development of a national program and summarizes the roles of government and the private sector in landslide mitigation nationwide.

U.S. Geological Survey Open File-Report 85–276–A, Landslide Classification for Identification of Mud Flows and other Landslides (Campbell and others, 1985), resulted from a joint study by the USGS and FEMA to evaluate the feasibility of delineating landslide hazards nationwide.

Landslides Investigation and Mitigation, Special Report 247 (Transportation Research Board, National Research Council, 1996, National Academy Press), provides a summary of the state-of-the-science of landslide hazard research, mapping, and assessment in the United States.

National Mitigation Strategy—Partnerships for Building Safer Communities (Federal Emergency Management Agency, 1996) provides a framework for mitigation of all natural hazards in the United States.

The Impacts of Natural Disasters—A Framework for Loss Estimation (Board on Natural Disasters, National Research Council, 1999, National Academy Press) recommends compilation of a comprehensive data base on losses from natural disasters.

U.S. Geological Survey Circular 1182, Land Subsidence in the United States (Galloway, Jones, and Ingebritsen, eds., 1999), explores the role of underground water in human-induced land subsidence through case histories.

Disasters by Design—A Reassessment of Natural Hazards in the United States (Mileti, 1999, Joseph Henry Press) provides an overview of what is known about managing natural hazard disasters, recovery, and mitigation.

Appendix 2. Meetings with Stakeholders

In 1999 and 2000, meetings among various stakeholder organizations were held to obtain input into a national strategy to mitigate landslide hazards. Attendees included State geologists, private consultants and university professors concerned with landslide hazards, and Federal, State and local government officials whose responsibilities include landslide hazard loss reduction. Many of their recommendations have been incorporated into the strategy either through input at meetings or subsequent reviews of this report. The meetings and participants are listed below.

Landslide Hazards Mitigation Stakeholders Meeting
State Geologists meeting
Philadelphia, Pennsylvania
January 16–17, 1999

Attendee	Title	Organization
Lee Allison	State Geologist	Kansas Geological Survey
John Beaulieu	State Geologist	Oregon Department of Geology and Mineral Industries
Tom Berg	State Geologist	Ohio Geological Survey
Vicki Cowart	State Geologist	Colorado Geological Survey
Jim Davis	State Geologist	California Department of Mines and Geology
Charles Gardner	State Geologist	North Carolina Geological Survey
Don Hoskins	State Geologist	Pennsylvania Geological Survey
John Kiefer	Assistant State Geologist	Kentucky Geological Survey
William Shilts	State Geologist	Illinois Geological Survey
Randy Updike		U.S. Geological Survey
Lynn Highland		U.S. Geological Survey
John Filson		U.S. Geological Survey

Landslide Hazards Mitigation Stakeholders Meeting
Private sector meeting
Albuquerque, New Mexico
February 23–24, 1999

Attendee	Title/Company	Location
Don Banks	Consultant	Vicksburg, Mississippi
Bill Cotton	Cotton, Shires & Associates, Inc.	Los Gatos, California
Bruce Clark	Leighton & Associates, Inc.	Irvine, California
Lloyd Cluff	Pacific Gas & Electric	San Francisco, California
Richard Gray	GAI Consultants, Inc.	Monroeville, Pennsylvania
Jim Hamel	Hamel Geotechnical Consultants	Monroeville, Pennsylvania

G.P. Jayaprakash	NRC Transportation Research Board	Washington, D.C.
Jeff Keaton	AGRA Earth and Environmental, Inc.	Phoenix, Arizona
George Kiersch	Kiersch Associates	Tucson, Arizona
George Mader	Spangle Associates	Portola Valley, California
Ralph Peck	Consultant	Albuquerque, New Mexico
Bill Roberds	Golder Associates	Redmond, Washington
Roy Shelmon	Consultant	Newport Beach, California
Rex Baum	U.S. Geological Survey	Golden, Colorado
Randy Updike	U.S. Geological Survey	Golden, Colorado

Landslide Hazards Mitigation Stakeholders Meeting
Academic sector meeting
Albuquerque, New Mexico
February 26–27, 1999

Attendee	University/Organization
Ed Cording	University of Illinois
Herbert Einstein	Massachusetts Institute of Technology
Arvid Johnson	Purdue University
Howard Kunreuther	Wharton School, University of Pennsylvania
David Montgomery	University of Washington
Rob Olshansky	University of Illinois
Nick Sitar	University of California
Keith Turner	Colorado School of Mines
Erik VanMarcke	Princeton University
Bob Watters MacKay	School of Mines, University of Nevada
Bob Fleming	U.S. Geological Survey, Golden, Colorado
Randy Updike	U.S. Geological Survey, Golden, Colorado

Landslide Hazards Mitigation Strategy Summit Meeting
San Antonio, Texas
August 31–September 1, 1999

Attendee	Organization
David Applegate	American Geological Institute
Rex Baum	U.S. Geological Survey, Golden, Colorado
Steven R. Bohlen	U.S. Geological Survey, Reston, Virginia
Bruce Clark	Leighton & Associates
Timothy Coh	U.S. Geological Survey, Reston, Virginia
Derek Cornforth	Landslide Technology, Portland, Oregon
Vicki Cowart	Colorado Geological Survey
Kim Davis	California Department of Conservation
Anthony de Souza	National Research Council
Robert Fakundiny	New York Geological Survey
John Filson	U.S. Geological Survey, Reston, Virginia
John Grant	National Aeronautics and Space Administration
Robert Hamilton	National Research Council

Lynn Highland	U.S. Geological Survey, Golden, Colorado
G.P. Jayaprakash	NRC Transportation Research Board
Arvid Johnson	Purdue University
Jeff Keaton	AGRA Earth & Environmental, Inc., Phoenix, Arizona
Pat Leahy	U.S. Geological Survey, Reston, Virginia
Lindsay McClelland	National Park Service
Doug Morton	U.S. Geological Survey, Riverside, California
Robert Olshansky	University of Illinois, Urbana/Champaign
John Pallister	U.S. Geological Survey, Reston, Virginia
William Roberds	Golder Associates, Redmond, Washington
William Shilts	Illinois State Geological Survey
Elliott Spiker	U.S. Geological Survey, Reston, Virginia
Randy Updike	U.S. Geological Survey, Golden, Colorado
Erik Van Marcke	Princeton University
Tom Yorke	U.S. Geological Survey, Reston, Virginia

Landslide Hazards Mitigation Stakeholders Meeting
Land-use planners meeting
Chicago, Illinois
February 17–18, 2000

Attendee	Organization
Steven Briggs	Cincinnati Planning Department
Paula Gori	U.S. Geological Survey, Reston, Virginia
James A. Hecimovich	American Planning Association
Lynn Highland	U.S. Geological Survey, Golden, Colorado
Sanjay Jeer	American Planning Association
George Mader	Spangle Associates, Portola Valley, California
Robert B. Olshansky	University of Illinois – Urbana-Champaign
Jane Preuss, AICP	GeoEngineers, Seattle, Washington
Daniel Sentz	Pittsburgh Department of City Planning
Elliott Spiker	U.S. Geological Survey, Reston, Virginia

Appendix 3. Landslide Hazards and Other Ground Failures—Causes and Types

Causes of Landslides

Landslide is a general term for a wide variety of downslope movements of earth materials that result in the perceptible downward and outward movement of soil, rock, and vegetation under the influence of gravity. The materials may move by falling, toppling, sliding, spreading, or flowing. Some landslides are rapid, occurring in seconds, whereas others may take hours, weeks, or even longer to develop.

Although landslides usually occur on steep slopes, they also can occur in areas of low relief. Landslides can occur as ground failure of river bluffs, cut and-fill failures that may accompany highway and building excavations, collapse of mine-waste piles, and slope failures associated with quarries and open-pit mines. Underwater landslides usually involve areas of low relief and small slope gradients in lakes and reservoirs or in offshore marine settings.

Landslides can be triggered by both natural changes in the environment and human activities. Inherent weaknesses in the rock or soil often combine with one or more triggering events, such as heavy rain, snowmelt, changes in ground water level, or seismic or volcanic activity. Long-term climate change may result in an increase in precipitation and ground saturation and a rise in ground-water level, reducing the shear strength and increasing the weight of the soil. Erosion can remove the toe and lateral slope support of potential landslides. Storms and sea-level rise often exacerbate coastal erosion and landslides. Earthquakes and volcanoes often trigger landslides.

Human activities triggering landslides are usually associated with construction and changes in slope and surface-water and ground-water levels. Changes in irrigation, runoff, and drainage can increase erosion and change ground-water levels and ground saturation.

Types of Landslides

The common types of landslides are described below. These definitions are based mainly on the work of Varnes (Varnes, D.J., 1978, Slope movement types and processes, *in* Schuster and Krizek, eds., Special Report 176, Landslides—Analysis and control: Transportation Research Board, National Research Council, Washington, D.C., p. 12–13).

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falls Abrupt movements of materials that become detached from steep slopes or cliffs, moving by free-fall, bouncing, and rolling.

flows General term including many types of mass movement, such as creep, debris flow, debris avalanche, lahar, and mudflow.

- **creep** Slow, steady downslope movement of soil or rock, often indicated by curved tree trunks, bent fences or retaining walls, tilted poles or fences.

- **debris flow** Rapid mass movement in which loose soils, rocks, and organic matter combine with entrained air and water to form a slurry that then flows downslope, usually associated with steep gullies.

flows—Continued

- **debris avalanche** A variety of very rapid to extremely rapid debris flow.
- **lahar** Mudflow or debris flow that originates on the slope of a volcano, usually triggered by heavy rainfall eroding volcanic deposits, sudden melting of snow and ice due to heat from volcanic vents, or the breakout of water from glaciers, crater lakes, or lakes dammed by volcanic eruptions.
- **mudflow** Rapidly flowing mass of wet material that contains at least 50 percent sand-, silt-, and clay-sized particles.

lateral spreads Often occur on very gentle slopes and result in nearly horizontal movement of earth materials. Lateral spreads usually are caused by liquefaction, where saturated sediments (usually sands and silts) are transformed from a solid into a liquefied state, usually triggered by an earthquake.

slides Many types of mass movement are included in the general term "landslide." The two major types of landslides are rotational slides and translational landslides.

> **rotational landslide** The surface of rupture is curved concavely upward (spoon-shaped), and the slide movement is more or less rotational. A slump is an example of a small rotational landslide.
>
> **translational landslide** The mass of soil and rock moves out or down and outward with little rotational movement or backward tilting. Translational landslide material may range from loose, unconsolidated soils to extensive slabs of rock and may progress over great distances under certain conditions.

submarine and subaqueous landslides Include rotational and translational landslide, debris flows and mudflows, and sand and silt liquefaction flows that occur principally or totally underwater in lakes and reservoirs or in coastal and offshore marine areas. The failure of underwater slopes can result from rapid sedimentation, methane gas in sediments, storm waves, current scour, or earthquake stresses. Subaqueous landslides pose problems for offshore and river engineering, jetties, piers, levees, offshore platforms and facilities, and pipelines and telecommunications cables.

topple A block of rock that tilts or rotates forward and falls, bounces, or rolls down the slope.

Appendix 4. Landslide Hazards Mitigation Strategies

Over the past few decades, an array of techniques and practices has evolved to reduce and cope with losses from landslide hazards. Careful land development can reduce losses by avoiding the hazards or by reducing the damage potential. Landslide risk can be reduced by the following five approaches used individually or in combination to reduce or eliminate losses.

Restricting development in landslide-prone areas.—Land-use planning is one of the most effective and economical ways to reduce landslide losses by avoiding the hazard and minimizing the risk. This minimization is accomplished by removing or converting existing development or discouraging or regulating new development in unstable areas. In the United States, restrictions on land use generally are imposed and enforced by local governments by land-use zoning districts and regulations. Implementation of avoidance procedures has met with mixed success. In California, extensive restriction of development in landslide-prone areas has been effective in reducing landslide losses. For example, in San Mateo County, California, since 1975 the density of development has been limited in landslide-susceptible areas. However, in many other States, there are no widely accepted procedures or regulations for avoiding or minimizing landslides.

Standardizing codes for excavation, construction, and grading.—Excavation, construction, and grading codes have been developed for construction in landslide-prone areas; however, there is no nationwide standardization. Instead, State and local government agencies apply design and construction criteria that fit their specific needs. The city of Los Angeles has been effective in using excavation and grading codes as deterrents to landslide activity and damage on hillside area. The Federal Government has developed codes for use on Federal projects. Federal standards for excavation and grading often are used by other organizations in both the public and private sectors.

Protecting existing development.—Control of surface-water and ground water drainage is the most widely used and generally the most successful slope-stabilization method. Stability of a slope can be increased by removing all or part of a landslide mass or by adding earth buttresses placed at the toes of potential slope failures. Restraining walls, piles, caissons, or rock anchors are commonly used to prevent or control slope movement. In most cases, combinations of these measures are used.

Utilizing monitoring and warning systems.—Monitoring and warning systems are utilized to protect lives and property, not to prevent landslides. However, these systems often provide warning of slope movement in time to allow the construction of physical measures that will reduce the immediate or long-term hazard. Site-specific monitoring techniques include field observation and the use of various ground motion instruments, trip wires, radar, laser beams, and vibration meters. Data from these devices can be telemetered for real-time warning.

Development of regional real-time landslide warning systems is one of the more significant areas of landslide research. One such system was successfully developed for the San Francisco Bay region, California, by the USGS in cooperation with National Oceanic and Atmospheric Administration and the National Weather Service. The system is based on relations between rainfall intensity and duration and thresholds for landslide initiation, geologic determination of areas susceptible to landslides, real-time monitoring of a regional network of rain gages, and National Weather Service precipitation forecasts.

Providing landslide insurance and compensation for losses.—Landslide insurance is a logical means to provide compensation and incentive to avoid or mitigate the hazard. Landslide insurance coverage could be made a requirement for mortgage loans. Controls on building, development, and property maintenance would need to accompany the mandatory insurance. Insurance and appropriate government intervention can work together, each complementing the other in reducing losses and compensating victims. However, landslide insurance is essentially absent across the Nation, except for mine subsidence coverage in eight States and some coverage for landslides due to earthquakes, if earthquake insurance is purchased, and minimal coverage for mudslides by the National Flood Insurance Program (Federal Emergency Management Agency).

The primary reason that insurance companies do not offer landslide insurance is the potential for adverse selection by the insured population. In addition, if available, it is likely that only those individuals in the most hazardous areas would buy private landslide insurance. This limited customer base would lead to very high premiums, perhaps nearly equal to the value of the property. An alternative to private sector insurance is a public insurance program, possibly modeled after the National Flood Insurance Program. Incentives to mitigate landslide hazards must also accompany insurance coverage, much like fire preventive incentives appear on current homeowners insurance polices.

A major obstacle to implementing some form of landslide insurance is the lack of technical information, maps, and assessments of landslide hazards. A joint study in 1985 by the USGS and the Federal Emergency Management Agency examined the feasibility of a nationwide program for identification and delineation of hazards from mudflows and other landslides. That study concluded that landslide hazards can be evaluated and mapped nationwide through a systematic sequence of studies, ranging from regional to local in progressively more detail. The comprehensiveness and accuracy with which landslide hazards would be delineated could be balanced against the costs of the program.

Appendix 5. Landslide Hazards Maps and Risk Assessments

Public and private organizations need sound economic and scientific bases for making decisions about reducing landslide-related losses. Quantitative risk assessment is a widely used tool for making such decisions because it provides estimates of the probable costs of losses and various options for reducing the losses. Such assessments can be either site specific or regional.

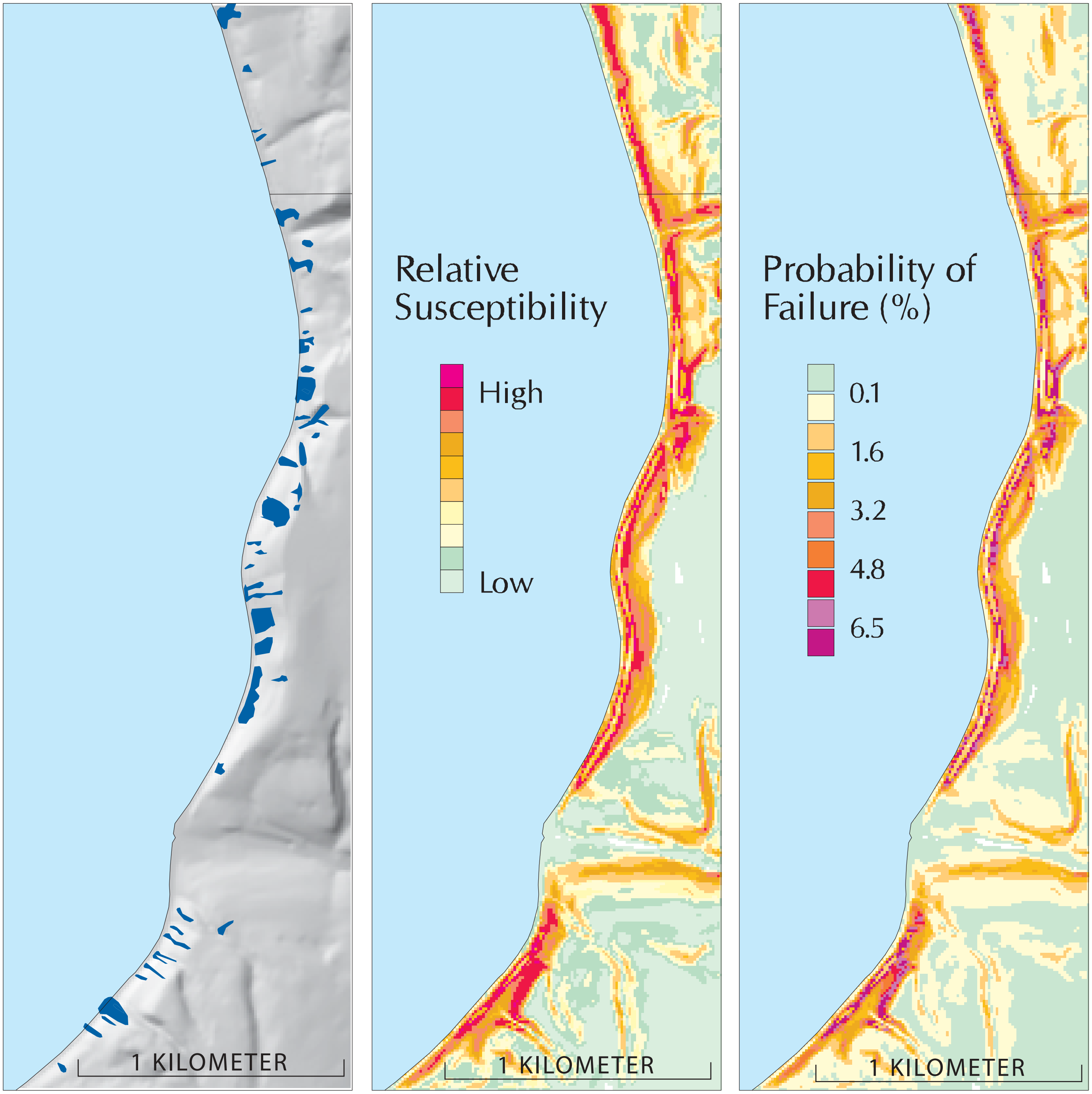
A risk assessment is based on the probability of the hazard and on an analysis of all possible consequences (property damage, casualties, and loss of service). Typically, private consultants with expertise in risk assessment, in cooperation with other partners or landowners, conduct risk assessments based on the results of the landslide susceptibility and probability studies. In many cases, private users such as insurance companies perform their own risk assessments from the probability data.

Regional landslide risk assessments can be accomplished through public and private partnerships involving the USGS, State Geological Surveys, local governments, and private consultants. In such a partnership (1) the USGS and the State Geological Surveys would cooperate to collect the basic geologic map data and landslide inventory data, (2) local governments would provide access to their detailed topographic data bases and records of landslide occurrence, and (3) the USGS would analyze the geologic, topographic, landslide, and other data to determine landslide susceptibility and probability.

Federal, State, and local government agencies, banks, and private landowners can use probability estimates and risk assessments to help identify areas where expected landslide losses are costly enough to justify remedial efforts or avoidance. More detailed studies can then be conducted in these areas to determine the optimal strategy for reducing landslide-related losses.

There are four types of landslide hazards maps—

- A landslide inventory map (fig. 5–1*A*) shows the locations and outlines of landslides. A landslide inventory is a data set that may represent a single event or multiple events. Small-scale maps may show only landslide locations, whereas large-scale maps may distinguish landslide sources from deposits and classify different kinds of landslides and show other pertinent data.
- A landslide susceptibility map (fig. 5–1*B*) ranks slope stability of an area into categories that range from stable to unstable. Susceptibility maps show where landslides may form. Many susceptibility maps use a color scheme that relates warm colors (red, orange, and yellow) to unstable and marginally unstable areas and cool colors (blue and green) to more stable areas.
- A landslide hazard map (fig. 5–1*C*, *D*) indicates the annual probability (likelihood) of landslides occurring throughout an area. An ideal landslide hazard map shows not only the chances that a landslide may form at a particular place but also the chances that a landslide from farther upslope may strike that place.
- A landslide risk map (fig. 5–1*E*) shows the expected annual cost of landslide damage throughout an area. Risk maps combine the probability information from a landslide hazard map with an analysis of all possible consequences (property damage, casualties, and loss of service).

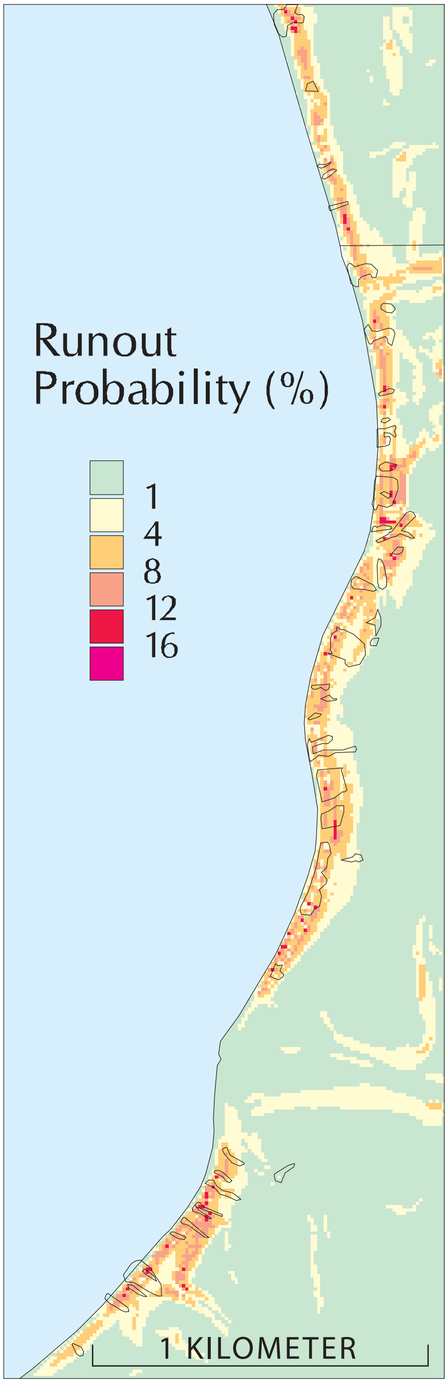


A, Inventory of landslides triggered by storms during the winter of 1996-97 overlain on a shaded-relief topographic base map (U.S. Geological Survey and Shannon and Wilson, Inc.).

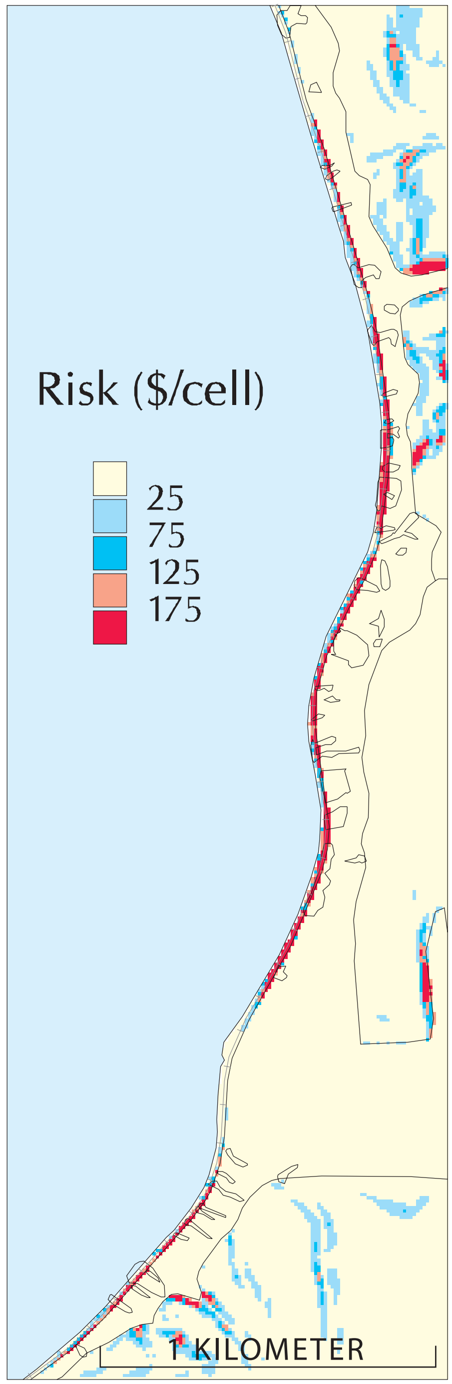
B, Landslide susceptibility (U.S. Geological Survey).

C, Probability of landslide occurrence given the event depicted in map *A* (U.S. Geological Survey and Shannon and Wilson, Inc.).

Figure 5–1. Maps showing some of the steps of a regional landslide risk assessment for part of Seattle, Washington. Names in parentheses indicate major contributors of data or analysis. *From* Baum, R.L., Harp, E.L., Michael, J.A., and Roberds, W.A., 2001, Regional landslide hazard assessment, an example from Seattle, Washington, *in* Zoghi, M., ed., Contemporary solutions to land mass stabilization: Proceedings of the 9th annual Great Lakes Geotechnical and Geoenvironmental Conference.



D, Landslide hazard map, which combines the results of map *C* with an assessment of landslide travel distance to show the probability of landslide damage (U.S. Geological Survey and Golder Associates).



E, Risk of loss due to landslides (U.S. Geological Survey and Golder Associates). Estimated cost of landslide-related losses in U.S. dollars.

Figure 5–1.—Continued

Appendix 6. Current Landslide Research, Mitigation Activities, and Responsibilities in the United States

Many Federal, State, and local agencies; academia; and private companies are involved in landslide research and mitigation in the United States; however, there is little coordination of landslide hazard mitigation activities. The need for information and cooperation spans the interests of many public and private organizations. The National Landslide Hazards Mitigation Strategy offers new opportunities for mutually advantageous partnerships related to hazard assessments, monitoring, and emergency response and recovery. Under the strategy, each level of government (Federal, State, and local), nongovernmental organizations, businesses, and individuals have some responsibility for mitigating, responding to, and recovering from landslide hazards.

Federal Agencies

The Federal role in hazard reduction has its origin in the Organic Act of 1879, which created the USGS. More recent legislation addressing the Federal role in landslide hazards includes the Dam Inspection Act of 1972, which stipulated responsibilities for landslide hazards affecting the safety of dams and reservoirs, and the 1974 Disaster Relief Act and subsequent reauthorizations, which gave the USGS responsibility to issue timely disaster warning of potential landslides.

The USGS Landslide Hazard Program is the only Congressionally authorized program dedicated to landslide hazards. The USGS National Landslide Information Center is a prototype clearinghouse for issuing advisories, press statements, and other information about landslides. The USGS has developed expertise in research, assessment, and mapping of landslide hazards and provides technical assistance during disaster response.

The National Science Foundation and the National Aeronautics and Space Administration fund landslide hazard research in the academic community. Personnel of the National Oceanic and Atmospheric Administration—National Weather Service (NWS) provide weather forecasts and assist in emergency response activities. Other Federal agencies, including the U.S. Army Corps of Engineers, Bureau of Land Management, Forest Service, National Park Service, Office of Surface Mining Reclamation and Enforcement, and Department of Transportation (especially the Federal Highway Administration) have landslide hazard experts and activities relating to lands and infrastructure under their jurisdiction.

The Federal Emergency Management Agency (FEMA) is responsible for emergency management and long-term mitigation of natural hazards including landslides. FEMA is the Federal coordinating agency for emergency response, disaster relief funding, and hazard mitigation efforts. The Federal Insurance and Mitigation Administration, a part of FEMA, provides insurance coverage for flood damages, including "mudslides." However, implementation has been difficult because of the absence of an accepted technical definition of a mudslide and an accepted methodology for delineating mudslide-hazard areas. Landslides other than mudslides are not insured under this program.

State and Local Government Agencies

While the Federal Government plays a lead role in funding and conducting landslide research, in developing landslide mapping and monitoring techniques, and in landslide hazard management on Federal lands, the reduction of landslide losses on other lands is primarily a State and local responsibility. A number of State agencies, commissions, and councils have responsibility for landslide hazards, including those with oversight of natural resources, transportation, geology, hazards, emergency services, and land-use issues.

States vary in their approaches to landslide hazards. Some States produce inventories of landslides and maps of landslide-prone areas for use by local government, business, and the public. However, landslide mapping has been done without widely accepted standards of accuracy, scale, and format. Some States monitor landslide-prone areas and provide expertise for response and recovery activities. Several States conduct research on landslide problems in their State, and a few States have regulatory authority.

The reduction of landslide losses through land-use planning and application of building and grading codes is the function of local government. Localities throughout the Nation differ in their regulatory authority and approach to reducing losses from landslide hazards. Local governments have the responsibility of issuing warnings of imminent landslides and managing emergency operations after a landslide. FEMA may become involved after a Presidentially declared disaster.

Landslide hazards have traditionally occupied a relatively modest place in public policy, embodied in zoning, legal liability, insurance, building codes, land use practices, and environmental quality. Maps showing historic landslides and areas susceptible to landslides have been used only sporadically for zoning and for purposes of real-estate disclosure. Building codes have been drafted for some localities to set minimum standards for construction on unstable slopes. Federal and State forestry practices in many localities include attention to landslide hazards. Building setbacks from coastal or riverine bluffs have been established in some areas on the basis of projected failure by landsliding. However, broad systematic policy approaches to landslide and other ground-failure hazards are rare, and most areas of the Nation lack the most fundamental technical information or policies to cope with their hazards.

Private and Academic Sectors

Private sector geologists, engineers, and building professionals are often involved in the identification and implementation of landslide reduction measures in building design and planning. University researchers study landslide processes and the development of monitoring and mitigation technologies and methods. These professionals provide advice to business and industry for loan, insurance, and investment decisions. Professional societies such as the American Society of Civil Engineers, the Association of Engineering Geologists, and the American Planning Association serve as conduits of information from researchers to practitioners and practitioners to researchers. Professional societies are generally the source of model codes, handbooks, and professional training for their membership, who in turn use the information to improve the state-of-knowledge of landslide loss reduction in the private and public sectors.

Appendix 7. Federal Agency Landslide Hazard Activities

The Federal role in landslide-hazard reduction involves numerous Federal agencies. The following Federal agencies provided descriptions of their landslide-hazard reduction activities. Contacts for various Federal agencies involved in landslide-hazard reduction are listed at the end of this appendix.

Department of Agriculture— Forest Service

The U.S. Department of Agriculture Forest Service is a land-management agency with responsibility for natural resources on national forests. Most of the national forest lands are located in the mountainous areas of the Western United States, including large parts of Alaska. The road system in national forests is comparable in size to many State road systems. Consequently, designing low volume roads to avoid landslide problems and repairing the damage to them from landslides are major tasks. Additionally, interstate and major State highways, railroad lines, oil and gas pipelines, and electric transmission corridors pass through the national forests. Assessing landslide hazards along such projects is increasingly important.

National forests generally occupy the headwaters of major rivers, increasing the importance of watershed management, especially for those watersheds where anadromous fisheries and significant inland fisheries are present. Increased landslide activity can produce sediment loads that degrade water quality and adversely affect fisheries habitat. Landslide hazard can be a more localized, but equally important, problem on national forests where development of large ski resorts, mines, or hydroelectric facilities takes place. Major wildfires can denude watersheds and lead to short-term landslide activity. The potential for loss of life and damage from debris flows initiated by precipitation events on burned watersheds must be considered in national forests, especially those having developed, private in-holdings and adjacent urban areas.

A primary landslide hazard activity conducted by Forest Service personnel is evaluating landslide hazard potential in environmental assessments or in reviewing environmental assessments prepared by forestry project proponents. Environmental or engineering geologists, as one of their primary duties, minerals geologists, as a related duty, or other earth scientists, where geologists are unavailable, carry out these evaluations. Engineering geologists and geotechnical engineers carry out environmental assessments and participate in designs to address landslide hazard to system roads.

Another activity is assessing damage from landslides following major natural disasters. The most formalized of these assessments is the Burned Area Emergency Rehabilitation procedure instituted during major wildfires. This activity also includes participating in development of stabilization and restoration projects to counter wildfire damage.

A national geographic information system (GIS) network of national forest lands and a data base that includes landslide information is under development. The landslide hazard information for this GIS is generated from USGS and State Geological Survey information and mapping by Forest Service geologists. The Research Branch of the Forest Service has contributed many studies that improve the understanding of landslide hazards relative to specific forest management activities.

—By Jerome DeGraff
Forest Service

Department of Commerce—National Oceanic and Atmospheric Administration

The National Oceanic and Atmospheric Administration (NOAA)—National Weather Service (NWS) is involved in landslide mitigation through its role in the Federal Response Plan and its mission of providing services for the protection of life and property. The National Weather Service works with other Federal, State, and local agencies by providing forecasts of hydrologic and meteorological conditions for landslide forecasts and mitigation efforts. This assistance may include on-scene meteorological personnel to assist in emergency response activities at landslides. The NOAA Weather Radio and other NWS dissemination systems broadcast "Civil Emergency Messages" concerning landslide warnings and response and recovery efforts at the request of local, State, and Federal emergency management officials.

—By Robert Livezey
National Oceanic and Atmospheric
Administration

Department of Defense— U.S. Army Corps of Engineers

As the premier, full-spectrum engineering organization of the United States military, the mission of the Corps of Engineers includes planning, design, building, and operating water resources and civil projects in the areas of flood control, navigation, environmental quality, coastal protection, and disaster response, as well as the design and construction of facilities for the Army, the Air Force, and other Federal agencies. In performing this broad mission, the Corps has addressed a full range of technical challenges associated with landslides and ground failure. Corps engineering geologists, geotechnical engineers, and geophysicists have been involved in the assessment, monitoring and analysis, and mitigation of landslides in a wide range of settings at locations around the world, as well as basic and applied research on topics directly related to the analysis and mitigation of landslides and ground failures.

Landslide assessment activities by Corps scientists and engineers have included investigations of landslides of various mechanisms and scales along navigable waterways such as the Mississippi and Ohio Rivers and that result in serious navigation hazards and threats to or loss of flood protection works. Landslides also play an important role in the erosion of the Nation's shoreline; the protection of shoreline is a major responsibility of the Corps. Many Corps dam-site investigations have involved the identification and assessment of past and potential landslides.

Corps engineering geologists, geotechnical engineers, and geophysicists have been involved in monitoring active landslides and ground failure in both natural and engineered soils and earth materials. These tasks have focused on identifying the temporal and spatial variability of earth movements and identifying causal factors. Monitoring data have been used along with detailed site information to analyze the stability of a landslide in terms of initial movements, present conditions, and conditions after mitigation actions.

As an engineering agency, the Corps has a significant role in the planning, design, and construction of landslide mitigation measures associated with the protection of its civil and military projects. Specific methods for reducing landslide hazards and increasing slope stability have been developed and implemented by Corps engineers at sites around the world. The Corps' role in initial engineering geological investigation, engineering analysis, remedial design, implementation, construction, and postproject monitoring is of particular value to the Nation and the international community.

The Corps has an important national mission in disaster response. This mission has involved the Corps in responding to landslides, especially those resulting from floods, hurricanes, volcanic eruptions, and earthquakes. In assistance to FEMA, Corps personnel have provided emergency assessments and immediate mitigation of past and potential landslides. The Corps' role in international disaster response has become a major focus in landslide engineering. Recent landslide assessments, analysis, and mitigation efforts have been conducted in Venezuela, Honduras, Nicaragua, Colombia, Peru, Haiti, Puerto Rico, South Korea, and the Philippines.

Research at the Corps' Engineering Research and Development Center includes the development and testing of analytical tools and assessment methods and approaches for landslide mitigation. Basic research in soil and rock mechanics, geomorphology, hydrogeology, remote sensing, geophysics, and engineering geology has resulted in advancements in the understanding of the causative factors and mechanics of landslides and ground failures.

—By Lawson Smith (deceased)
U.S. Army Corps of Engineers

Department of the Interior—Bureau of Land Management

The Bureau of Land Management is a Federal Agency that manages multiple uses of approximately 264 million surface acres of Federal land located primarily in 12 Western States. A relatively small portion of this land is located in steep mountainous terrain with geologic and climatic conditions resulting in high landslide hazards, such as in western Oregon, northern California, and northern Idaho.

Many landslides on public land are the result of natural disturbance events, but land-management activities, including road building, timber harvest, historic mining, and water impoundments, can contribute to their occurrence. The Bureau of Land Management does not have an agencywide landslide hazards program or specialized personnel. The bureau's local field office landslide hazards prevention activities include identification of unstable slopes by using aerial photograph interpretation, landslide hazards guides, on-site indicators, predictive models, and limited inventory and monitoring of landslides.

Prevention and mitigation of landslides are accomplished by using a variety of methods. Existing roads may be closed and obliterated, rerouted, or kept open and stabilized with additional runoff control structures, subsurface drainage control, or other techniques. Routine road maintenance is an important factor in helping to reduce landslide hazards. Prudent route analysis and design to minimize landslide hazard are employed for new roads in landslide prone areas. Hazardous-fuels management can reduce the risk of catastrophic wildfires that could increase landslide hazards. Timber management silvicultural practices are employed to maintain root strength where needed for slope stability. Sites that are a threat to human health and safety, roads and recreational facilities, water quality, fisheries and aquatic habitat, and other resource values are stabilized, and sediment is controlled with revegetation and structural controls.

—By William Ypsilantis
Bureau of Land Management

Department of the Interior—National Park Service

Many national parks are geologically active, exposing park visitors, staff, and infrastructure to geologic hazards. Landslides, including slope failures, mudflows, and rockfalls, adversely affect parks, causing deaths and injuries, closing roads and trails, and damaging park infastructure. Recent examples include several rockfalls in Yosemite Valley, each with one fatality; damaging landslides in Shenandoah National Park triggered by torrential rains; repeated slope failures fed by artificial aquifers at Hagerman Fossil Beds National Monument; landslides that closed roads in Zion and Yellowstone National Parks; and the threat of large debris flows at Mt. Rainier. USGS scientists have provided insights essential to effective response to landslides hazards at these and other national parks.

Because it is a natural process, landslide activity is generally allowed to proceed unimpeded in national parks unless safety is a concern. However, where people have destabilized the landscape (for example, by logging, mining, and road building), disturbed lands are restored where practical to their pre disturbance condition.

To reduce risk from landslides and other geologic hazards, park planners must incorporate information from hazard assessments and maps into decisions about appropriate sites for facilities such as campgrounds, visitor centers, and concession areas. Planners face difficult choices as they attempt to balance risks from different hazards, such as floods and rockfalls in confined valleys, and at the same time provide public access to popular but potentially hazardous areas. When a landslide or other hazard occurs, park personnel must quickly rescue people, stabilize structures, and clear debris from roads and other public areas. Then park personnel must work with experts to assess the nature and extent of the event and the risk of recurrence. Short-term studies are required to help managers decide whether and when to reopen affected areas; then more detailed research is often needed to make informed decisions about future use of the immediately affected area and other areas that may face similar hazards.

Park interpretive programs inform visitors about key resources and issues, enabling the public to better understand geologic hazards. Interpreters communicate directly with visitors through programs such as nature walks and campfire presentations, as well as through exhibits in visitor centers and, in some cases, books and videos sold by cooperating associations and concessionaires. The National Park Service is increasingly reaching out to a broader audience, many of whom may not have the opportunity to visit parks, through innovative methods such as school programs and Web sites. Interpreters work in partnership with the scientific community to ensure that complex information can be conveyed accurately and in a form that is comprehensible and relevant to nonspecialists.

These and other park programs welcome additional help to assess landslide hazards in parks, provide input to park planning so that infrastructure can be located away from zones of greatest landslide risk, respond quickly after significant landslide events, and improve communication with the public.

—By Lindsay McLelland
National Park Service

Department of the Interior—Office of Surface Mining Reclamation and Enforcement

The Office of Surface Mining's (OSM) role in landslide mitigation is confined to those landslides that are related to past coal mining activity, as authorized by the Surface Mining Control and Reclamation Act. A coal mining technique in the Appalachians involving mountaintop removal and valley filling is monitored by OSM to prevent serious landslides. Most abandoned mine land landslide areas are reclaimed through State or Indian Tribe abandoned mine land programs, funded with OSM grants. The Office of Surface Mining, through its Federal Reclamation Program, has responsibility for those States and Tribes that do not have approved programs.

When there is an immediate danger to the occupants of dwellings caused by a landslide, abatement actions are taken immediately through OSM or State emergency programs. Otherwise, landslide problem areas that endanger human health, safety, and general welfare are assigned priorities, and mitigation actions are taken based on the highest priority.

Reclamation records, maintained in OSM's Abandoned Mine Land Inventory System, indicate that OSM and the States and Tribes have completed reclamation on 3,367 acres of dangerous slides at a cost of $125.25 million. Also, 651 acres are designated as high priority and have been funded, but not yet reported as completed, at $30.69 million. An additional 2,276 acres, with an estimated cost of $73.77 million, are unfunded.

—By Gene Krueger
Office of Surface Mining Reclamation and Enforcement

Department of the Interior—U.S. Geological Survey

The U.S. Geological Survey (USGS) directly or indirectly funds and maintains landslide hazard expertise in several of its programs. The following programs direct research and assessment of landslides, debris flows, and lahars caused by storms, earthquakes and volcanoes, submarine landslides, and riverine and coastal erosion.

USGS Landslide Hazards Program.—The USGS Landslide Hazards Program supports hazard investigations and assessments, research on monitoring and forecasting landslides, landslide emergency response, operation of the National Landslide Information Center in Golden, Colorado, and research and assessment for the implementation of mitigation strategies for Federal, State, and local land-management and emergency-response agencies. The information generated also provides a basis for land-use planning, emergency planning, and private decision-making, including insurance and financial incentives. Much of the current work is being conducted in the Pacific Northwest, California, and the Blue Ridge Mountains in the Eastern United States; most real-time monitoring activities are taking place in Washington, California, New Mexico, and Colorado.

Earthquake Hazards Program.—The USGS National Earthquake Hazards Reduction Program supports USGS studies and external, cooperative studies of landslides caused by earthquakes, including liquefaction investigations in California. It also supports seismic instrumentation of landslide sites.

Volcano Hazards Program.—The Volcano Hazards Program funds debris-flow research at the Cascades Volcano Observatory. The research includes field investigations at Mount St. Helens and Mount Rainier, Washington, and an experimental debris-flow flume in the Willamette National Forest, Oregon. The Volcano Disaster Assessment Program conducts lahar investigations internationally.

Coastal and Marine Geology Program.—The Coastal and Marine Geology Program focuses on coastal and submarine landslide studies. The areas of investigations include California, Washington, Alaska, Hawaii, and Lake Michigan. The program also conducts subsidence studies in Louisiana.

National Geologic Cooperative Mapping Program.—The National Geologic Cooperative Mapping Program supports comprehensive geologic mapping as a basis for landslide hazard assessment through the matching-fund STATEMAP grants program.

Earth Surface Dynamics Program.—The Earth Surface Dynamics Program supports research on landslide processes and climate history in the Blue Ridge in the Eastern United States.

Water Resource Programs.—Water Resource programs conduct research on landslides, debris flows, subsidence, and riverine and coastal erosion. Research is also supported through USGS District Offices in Hawaii, Puerto Rico, and other States as landslides occur.

—By Paula L. Gori
U.S. Geological Survey

Department of Transportation—Federal Highway Administration

The Federal Highway Administration (FHWA) is a part of the Department of Transportation, with field offices across the United States. The FHWA performs its mission primarily through the following two programs:

- The Federal-Aid Highway Program provides Federal financial assistance to the State Departments of Transportation to construct and improve the National Highway System, urban and rural roads, and bridges. The program provides funds for general improvements and development of safe highways and roads.
- The Federal Lands Highway Program provides access to and within national forests, national parks, Indian reservations, and other public lands by preparing plans, letting contracts, supervising construction facilities, and conducting bridge inspections and surveys.

In support these program areas, the FHWA conducts and manages a comprehensive research, development, and technology program.

The FHWA has recognized a need for consistent understanding and application of soil and rock slope stability analysis and mitigation for highway projects across the United States. These analyses generally are carried out throughout the life of most highway projects; that is, during planning, design, construction, improvement, rehabilitation, and maintenance. Planners, engineers, geologists, contractors, technicians, and maintenance workers are involved in the process.

To this end, the FHWA geotechnical engineering program continues to develop and support the development of training courses, design manuals, demonstration projects, and geotechnical software. The FHWA geotechnical engineering program maintains an ongoing dialogue and exchange of information with and among State Departments of Transportation through annual Regional Geotechnical Meetings, training courses, and technical assistance provided through the FHWA Resource Centers.

—By Barry D. Siel
Federal Highway Administration

Department of Transportation—Federal Railroad Administration

The Federal Railroad Administration's (FRA) primary mission is to promote and regulate railroad safety. To support its mission, the FRA sponsors research projects to develop and demonstrate techniques for advancing railroad safety and for improving railroad operating and maintenance practices.

As with any surface transportation, landslides can threaten the safety of railroad operations, but landslide mitigation planning and implementation for railroads must consider the following characteristics of railroad operations and of the U.S. railroad network. First, warnings must allow for trains to safely stop in advance of a hazard. For heavy freight trains or faster passenger trains on descending grades, stopping distances are often 1 to 2 miles. Second, trains cannot steer around even the smallest slides or obstructions. And third, especially in the Western United States, there are relatively few alternative railroad routes, and the detour distances for accessing these may be hundreds of miles long.

Landslide mitigation methods on railroads are similar to those used for highway transport, mainly slide fences, rock or slide sheds (in areas of frequent, heavy slides), and anchoring or stabilization of unstable rock or soil slopes. Slide fences are often tied into the signal systems, so that any slide of sufficient intensity to break wires in the fence will cause the signals protecting the nearby section of track to show a stop indication; the train dispatcher may also receive an indication. Because of the mitigation efforts that the railroad industry has taken, serious accidents, injuries, and fatalities due to slides are relatively few, but there are still a considerable number of disruptions and delays due to slide events.

Recent FRA landslide mitigation activities include sponsoring the demonstration of two techniques in the Northwest Corridor (between Vancouver, British Columbia, and Eugene, Oregon) –

- A cellular confinement method for stabilizing slopes subject to failure by weathering and erosion of the surface layer and
- A method to install liquid level sensors for indicating slope movement

In addition, the FRA, along with the Association of American Railroads (AAR) and the National Center for Atmospheric Research (NCAR), sponsored a symposium in 2001 on Enhanced Weather Information for Railroad Productivity and Safety. A major focus of this symposium was weather and weather events as causes or triggers of natural hazards, including landslides. The FRA also participated in the May 2002 Canadian workshop on Natural Hazard Mitigation on Railroads. This workshop focused on addressing research needs for hazard risk management, hazard characterization (prediction of frequency and magnitude), and monitoring and detection technology.

Railroad landslide mitigation needs and ideas resulting from the 2001 FRA/AAR/NCAR symposium and the 2002 Natural Hazard workshop were consistent with the objectives of the National Landslide Hazards Mitigation Strategy, particularly with respect to the need for improved understanding of slide triggers, better monitoring and detection technology, and the potential benefits of sharing information among different transportation and communications organizations with facilities and operations close to active slide areas. The FRA will continue to support work in these areas in partnership with the railroad and research communities.

—By Donald Plotkin
Federal Railroad Administration

Federal Emergency Management Agency

The Federal Emergency Management Agency (FEMA) has many roles in landslide hazard loss reduction. FEMA has responsibilities in emergency response, disaster recovery assistance, and promotion of landslide hazard mitigation. FEMA coordinates the Federal Government's response to disasters such as earthquakes, hurricanes, and volcanic eruptions that include landslides through the Federal Response Plan. The agency provides financial assistance to State and local governments for repair of public facilities damaged during these disasters, including replacement of lost fill and construction of fill-retaining devices such as gabions and rock toes. Following disasters, the agency also supports installation of mitigation measures, such as installing drainage ditches to direct flow away from the landslide areas.

FEMA provides relief to individuals who have sustained losses due to mudslides and who are insured under the National Flood Insurance program. However, the distinctions that the agency makes between landslides and mudslides have been a source of controversy, as the agency provides only limited damage coverage. Also encouraging mitigation measures in tandem with insurance coverage, which is a cornerstone of the flood insurance program, has been impossible because, to date, there are no maps that delineate mudslide zones and no standards governing development in mudslide-prone areas.

FEMA promotes landslide-hazard mitigation by developing State and national guidebooks for landslide loss reduction, including a prototype mitigation plan that can be incorporated into existing hazard mitigation plans. Through its Disaster-Resistant Communities project, FEMA is encouraging local jurisdictions to implement mitigation programs that reduce, among other hazards, landslides.

—By Ed Pasterick
Federal Insurance Administration

National Science Foundation

According to the National Science Foundation Act of 1950, the mission of the National Science Foundation (NSF) is to promote the progress of science; to advance the national health, prosperity, and welfare; and to secure the national defense. The NSF provides funding for landslide and slope stability research through several programs—

- The Geotechnical and GeoHazards Systems (GHS) Program (http://www.eng.nsf.gov/cms/ghs.htm), under the Division of Civil and Mechanical Systems in the Directorate for Engineering (CMS/ENG)
- The Hydrologic Sciences Program and the Geology and Paleontology Program, under the Division of Earth Sciences in the Directorate for Geosciences (EAR/GEO)

In the Directorate for Engineering, funding mechanisms include peer reviewed unsolicited proposals, support for workshops, Small Grants for Exploratory Research, and the CAREER Program (http://www.nsf.gov/pubsys/ods/getpub.cfm?gp). The GHS Program does not have solicitations directed specifically toward landslide and slope stability research; all current research in this area is the result of unsolicited proposals. Historically, GHS has supported development of numerical analysis techniques for slope stability, landslide mitigation techniques, investigations of seismic slope stability and earthquake induced submarine landslides, constitutive and rheological model development related to slope stability and mud and debris flows, and post-landslide reconnaissance. Current GHS-funded research includes development of probabilistic methods of stability analysis, analysis of the role of strain localization and dilatancy on slope stability, development of Time Domain Reflectometry sensors for early warning of slope movement, using geographic information systems to evaluate the factors controlling seismic slope stability, and stabilization of slopes by using in-situ reinforcement.

In the Directorate for Geosciences, the Hydrologic Sciences Program supports work on landslide triggering caused by high water contents in soils and lubricating slip planes between strata; the Geology and Paleontology Program focuses on the role of landslides in reshaping the Earth's surface. Both programs interact with other NSF earth science programs to study landslide triggering by earthquakes or volcanic events. Projects include studies on diffusive soil transport as a process in hillslope evolution and studies on reconstructing landslide history. The NFS is also starting a Science and Technology Center at the University of Minnesota; here new analytical tools will be refined and developed to study the various processes that sculpt the Earth's surface. A major focus will be the study of the patterns in which landslide materials accumulate over sequential events. The simulation of this process is receiving growing attention as a tool in mapping aquifer properties.

—By Richard J. Fragaszy
National Science Foundation

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