DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

National Landslide Hazards Mitigation Strategy

A FRAMEWORK FOR LOSS REDUCTION

U.S. GEOLOGICAL SURVEY
OPEN-FILE REPORT 00-450
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A FRAMEWORK FOR LOSS REDUCTION

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Preface

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

House Report 106-222 accompanying the Interior Appropriations Bill for FY 2000, which was 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."

Acknowledgments

This report was written by Elliott Spiker and Paula Gori of the USGS, 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. This report benefited from contributions and reviews from 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.

Cover Photo: *A landslide near McClure Pass, Colorado, in 1994 - This area of the Rocky Mountains has chronic problems where roads cross landslide areas. This car plunged into the landslide in the middle of the night, soon after the landslide occurred. Fortunately, no one was injured. Photograph by Terry Taylor, Colorado State Patrol.*

September 2000

USGS
science for a changing world

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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

In response to the rising costs from landslide hazards in the United States, this report outlines key elements of a comprehensive and effective national strategy for reducing losses from landslides nationwide, including activities at the national, State, and local levels, in both the public and private sectors. It provides an assessment of the status, needs, and associated costs of this national landslide hazards mitigation strategy and is submitted in compliance with a directive of Public Law 106-113 (see Preface). 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*.

The strategy outlined in this report gives the Federal government a prominent role in leading 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 preparing this strategy on behalf of the large multi-sector, multi-agency stakeholder group involved in landslide hazards mitigation. A broad spectrum of expert opinion was sought in developing this strategy report as requested by the Congress in House Report 106-222.

This report outlines the essential elements of a National Landslide Hazards Mitigation Strategy that when implemented would reduce the cost of landslide hazards. It includes developing new partnerships between government at all levels, academia, and the private sector, and expanding landslide research, mapping, assessment, real-time monitoring, forecasting, information management and dissemination, development of mitigation tools, and emergency preparedness and response. Such a strategy makes use of 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.

A 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 nine major elements, spanning a continuum from research to the formulation and implementation of policy and mitigation:

1. **Research:** Developing a predictive understanding of landslide processes and triggering mechanisms.
2. **Hazard Mapping and Assessments:** Delineating susceptible areas and different types of landslide hazards at a scale useful for planning and decision-making
3. **Real-Time Monitoring**: Monitoring active landslides that pose substantial risk.
4. **Loss Assessment**: Compiling and evaluating information on the economic impacts of landslide hazards.
5. **Information Collection, Interpretation, and Dissemination**: Establishing an effective system for information transfer.
6. **Guidelines and Training**: Developing guidelines and training for scientists, engineers, and decision-makers.
7. **Public Awareness and Education**: Developing information and education for the user community
8. **Implementation of Loss Reduction Measures**: Encouraging mitigation action.
9. **Emergency Preparedness, Response, and Recovery**: Building resilient communities.

Table 1 on pages 25-26 describes the roles envisioned for Federal, State, and local governments, the private sector, and universities in each of the above nine elements. The USGS has a significant role in each element; however, the USGS is not the lead for all elements.

Landslide hazard mitigation requires interactive collaboration across societal boundaries of academia, government, and the private sector. Aggressive implementation of a comprehensive and effective national landslide hazards mitigation strategy would require 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 ($2.2 million total appropriation in FY2000) 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 State and local governments efforts to map and assess landslide hazards within their jurisdictions through competitive grants ($8 million annually to be augmented with 30% matching funds by the States and local jurisdictions)
- Establishment of a Cooperative Federal Land Management Landslide Hazard Program to increase the National Park Service, U.S. Forest Service, Bureau of Land Management, and other such organizations' capabilities 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 report advocates enhanced coordination among Federal, State, and local agencies to partner effectively with the academic and the private sectors and leverage shared resources under the leadership of the USGS.

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, USGS)*

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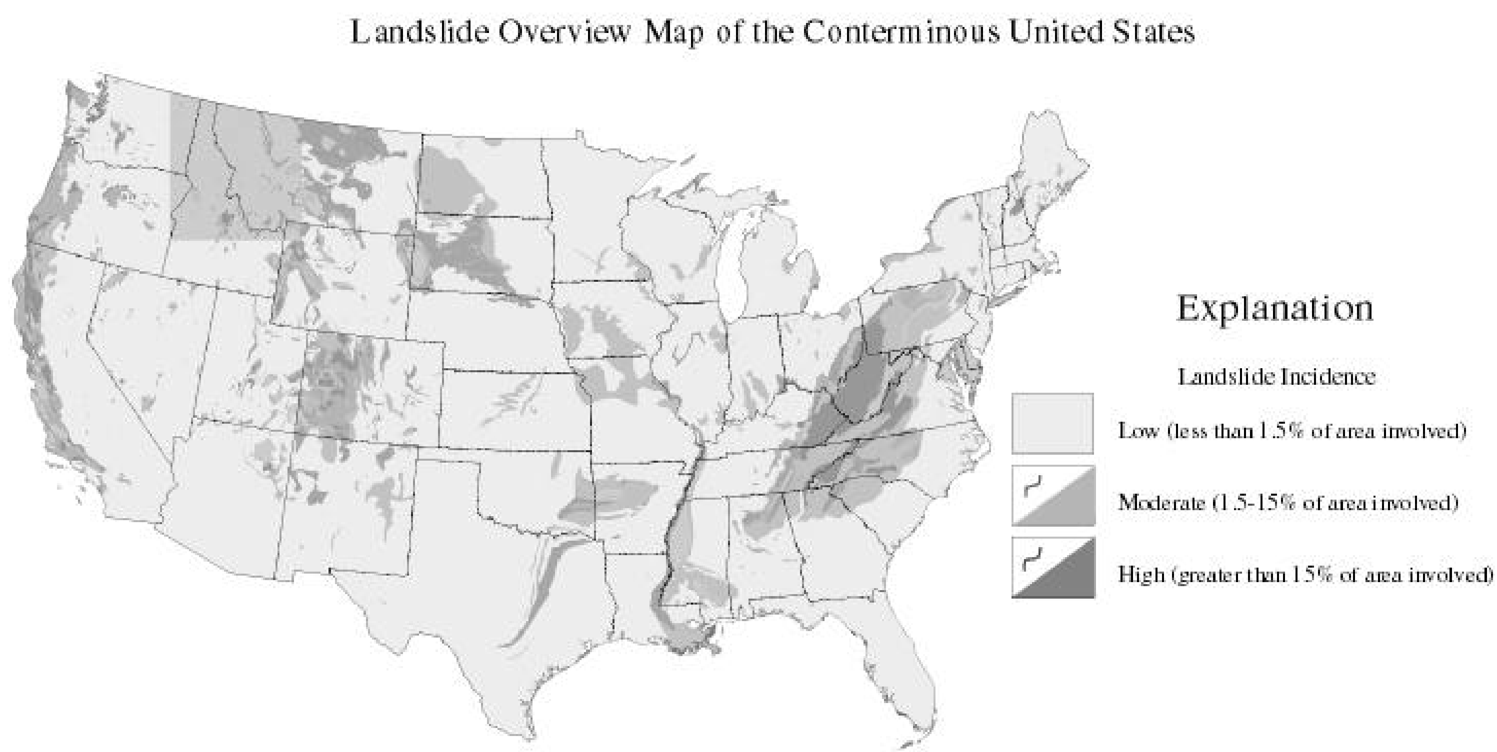


Landslide Overview Map of the Conterminous United States (USGS Open-file Report 97-289, digital compilation by Jonathan W. Godt, 1997). Different colors denote areas of varying landslide occurrence.

National Landslide Hazards Mitigation Strategy
A Framework for Loss Reduction

1. Introduction

Landslides and other forms of ground failure impact communities all across the Nation. Despite advances in science and technology, losses continue to result in human suffering, billions of dollars in property losses, and environmental degradation. As 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 implement mitigation measures. For many years, USGS, States, universities, and the private sector have been grappling with understanding and reducing landslide hazards, and an extensive body of knowledge exists. (See Appendix B for sources of information.) However, to achieve the goals of significantly reducing losses from landslide hazards, we need a much more comprehensive scientific understanding of landslides 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 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*.

(Photograph by R.L. Schuster, USGS)

Massive Landslide at Thistle, Utah

The 1983 Thistle landslide began moving in the spring of 1983 in response to groundwater 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, obliterating U.S. Highway 6 and the main line of the Denver and Rio Grande Western Railroad.

The town of Thistle was inundated under 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. Similarly, the highway 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, the most costly single landslide event in U.S. History.

As requested by the Congress in House Report 106-222, the USGS has prepared this National Landslide Hazards Mitigation Strategy on behalf of the large multi-sector, multi-agency stakeholder group involved in landslide research and mitigation nationwide. A series 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 A** for more information about the stakeholder workshops).

The National Landslide Hazards Mitigation Strategy (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 levels of government and the private sector.

The National Landslide Hazards Mitigation Strategy described here incorporates many ideas and recommendations of previous studies and reports that have expressed the need for a national strategy to address natural hazards, including landslides and other ground failures (see **Appendix B**). These 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 C** for more information about different types of landslide hazards and other forms of ground failure).

Debris flows like these near Glenwood Springs, Colorado, are a consequence of heavy rainfall on previously burned hillsides. (Photo: Jim Scheidt, U.S. Bureau of Land Management)

Wildfires and Debris-Flows

During the summer of 2000, numerous wildfires burned drought-parched areas of the western United States. USGS scientists were enlisted to advise Federal and State emergency response teams on the potential for future debris flows in burned areas, such as Cerro Grande fire (Los Alamos, New Mexico) and 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. A 3-mile length of the highway was inundated with 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 USGS Fact Sheet 176-97 "Debris-Flow Hazards in the United States," by Lynn M. Highland, Stephenson D. Ellen, Sarah B. Christian, and William M. Brown III

1.1. Losses from Landslide Hazards in the United States

Landslides are among the most widespread geologic hazard 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. Though most landslide losses in the United States accrue from many widely distributed events, thousands of landslides can be triggered by severe storms and earthquakes, 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 season 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 represent 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. Also, 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 in northwest Seattle, Washington. Foundation of house on right edge of photograph and decks of neighboring houses have been undermined.
(Photo by Alan F. Chleborad, USGS)

Project Impact: Building Disaster Resistant Communities

An outstanding example of public-private partnerships is FEMA's Project Impact. Nearly 200 communities and more than 1,100 business partners have embraced Project Impact since its inception in 1997. Instead of waiting for disasters to occur, Project Impact 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 Project Impact, Seattle partnered with USGS to develop landslide hazard maps that will enable the city to become better prepared for landslide emergencies and reduce losses resulting from landslide disasters. The city made available information needed by USGS scientists to accurately assess landslide hazards in the area and to ultimately produce a computer-based landslide hazard map, including Seattle's detailed topographic database and related geographic data, detailed precipitation data collected by the National Weather Service, GIS support for completing the maps, and a landslide database from city records that date back to the late 1800's. 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.

Project Impact 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.

Landslide losses are increasing in the United States and worldwide as development expands under pressures of increasing populations. This trend will continue due to development in hazardous areas, expansion of transportation infrastructure, deforestation of landslide-prone areas, and changing climate patterns. However, 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.

Landslides and other ground failures impose many direct and indirect costs to 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 large adverse effect on infrastructure and threaten lifelines, including transportation corridors, fuel and energy conduits, and communications linkages. Federal, State, local, and private roads, bridges, and tunnels suffer economically devastating effects from landsliding every year. Railroads, pipelines, electric and telecommunication lines, dams, offshore oil and gas production facilities, port facilities, and waste repositories continually experience the consequences of land movement. Road building and construction often exacerbate the landslide problem in hilly areas by altering the landscape, slopes and drainages, and 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.

1.2. A National Strategy

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 that is meaningful and useful for decisionmaking. Cost-effective actions can be taken to reduce the loss of lives and property, damage to the environment, and

Debris-Flow Flume—Understanding Landslide Processes

USGS and U.S. Forest Service (USFS) scientists recreate debris flows in a flume that has been constructed to conduct controlled experiments. Located about 45 miles east of Eugene, Oregon, in Willamette National Forest in the Cascades Range, this unique facility provides research opportunities available nowhere else in the United States. USGS and USFS scientists conduct experiments to improve 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 (pictured at right) is a reinforced concrete channel 95 meters (310 feet) long, 2 meters (6.6 feet) wide, and 1.2 meters (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. Eighteen 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 USGS Open File Report 92-483 by R.M Iverson, J.E. Costa, and R.G. LaHusen, 1992.

economic and social disruption caused by landslides and other ground failures (see **Appendix D** 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 dialogue among and concerted action by all sectors of our society.

A new public-private partnership is needed at the Federal, State, and local level 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 decision-making, and that such information is applied to mitigate these hazards.

2. A National Landslide Hazards Mitigation Strategy

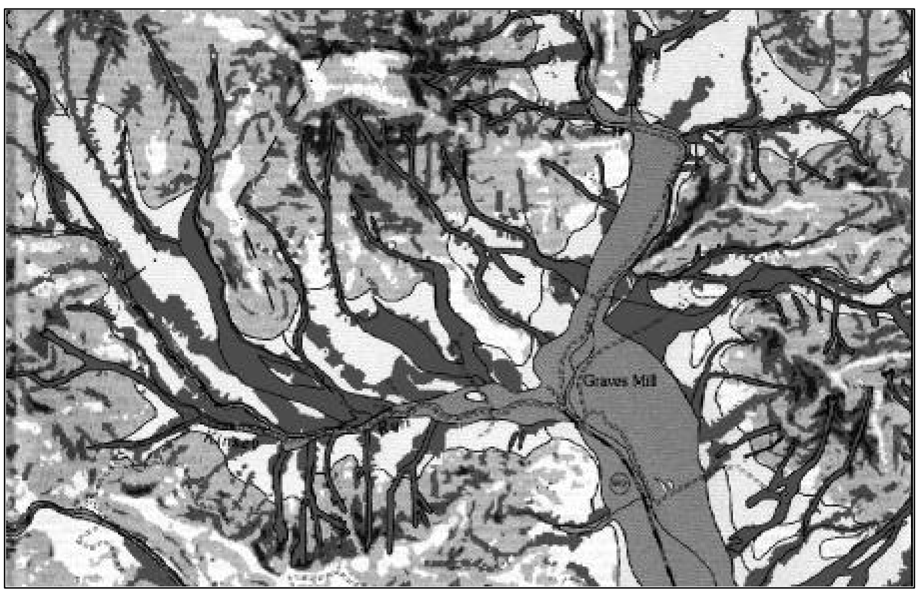
The National Landslide Hazards Mitigation Strategy described herein envisions a society that is fully aware of landslide hazards and routinely takes action to reduce both the risks and costs associated with those hazards. The Strategy envisions bringing together relevant scientific, engineering, construction, 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.

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, thirty 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.



Section of debris-flow hazard map, Madison County, Virginia (USGS I-2623B, by B.Morgan, G.Wieczorek, and R.Campbell, 1999).

Scientists from the USGS 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 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.

USGS Fact Sheet FS-159-96 "Debris-Flow Hazards in the Blue Ridge of Virginia" by Paula L. Gori and William C. Burton

2.1. Major Elements and Strategic Objectives

2.1.1. 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. Although the primary focus is on landslide hazards, the National Strategy provides a framework for addressing other forms of ground failure as well.

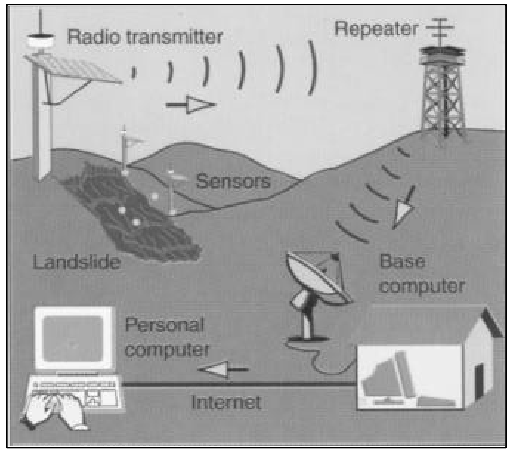
The USGS has a role in each of the nine elements as a provider of landslide hazard information; however, the lead and participants in each element differs with the nature of the element.

2.1.2. Elements and Objectives

1. **Research: Developing a predictive understanding of landslide processes and triggering mechanisms, led by 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 would increase the Nation's capability to forecast landslide hazards through enhanced research and application of new technology and understanding of landslide processes, thresholds, and triggering mechanisms.
    - Develop a national research agenda and a multi-year implementation plan based on the current state of scientific knowledge concerning landslide hazard processes, thresholds, and triggers, and 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.

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 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 other local, State, and Federal agencies, provide continuous real-time monitoring of landslide activity using a system developed by the USGS for monitoring active volcanoes in remote areas.



Network for transmission of real-time landslide data

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. 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.

Testing a solar-powered radio telemetry system for remote transmission of real-time landslide data. (Photo by Mark Reid, USGS)

Measuring landslide movement. (Photo by Richard LaHusen, USGS)

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

From USGS Fact Sheet 091-99, by M. Reid, R. LaHusen, and W. Ellis.

- 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).

2. **Hazard Mapping and Assessments: Delineating susceptible areas and different types of landslide hazards at a scale useful for planning and decision-making, led by 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 E** 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 prerequisite to producing probabilistic hazard maps and risk assessments, but these maps and data are not yet available in most areas of the United States.

   The following actions would provide the necessary maps and assessments, and other information to officials and planners to reduce risk and losses.

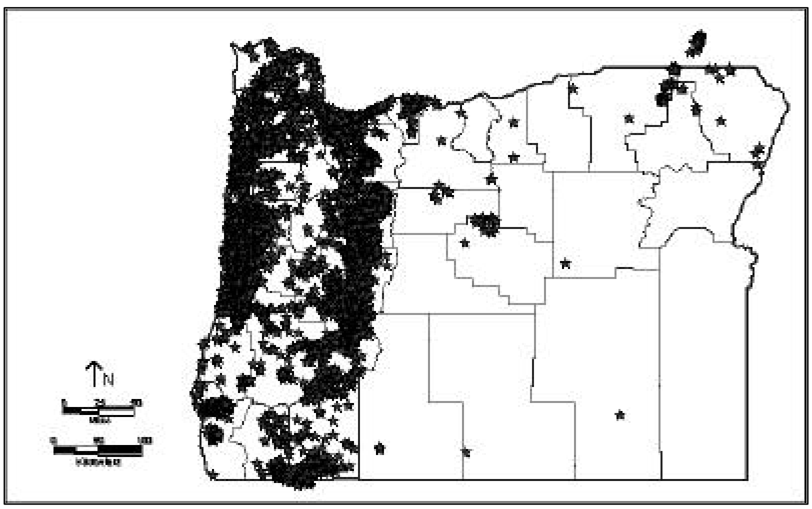
   - Develop and implement a plan for mapping and assessing landslide and other ground-failure hazards nationwide.
   - Develop an inventory of known landslide and other ground-failure hazards nationwide.
   - Develop and encourage the use of standards and guidelines for landslide hazard maps and assessments.

3. **Real-Time Monitoring: Monitoring active landslides that pose substantial risk, led by USGS.** Monitoring of 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

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 received 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, FEMA provided funding for the consolidation of a landslide inventory. 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.



Landslide inventory for three 1996/97 storm events in Oregon.

Over nine thousand 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 expected that two to three times this many landslides occurred during the time period. As shown on the schematic map, the vast majority (98%) 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.

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.

From Hofmeister, R.J., 2000,"Database of Slope Failures in Oregon for Three 1996/97 Storm Events," Oregon Department of Geology and Mineral Industries.

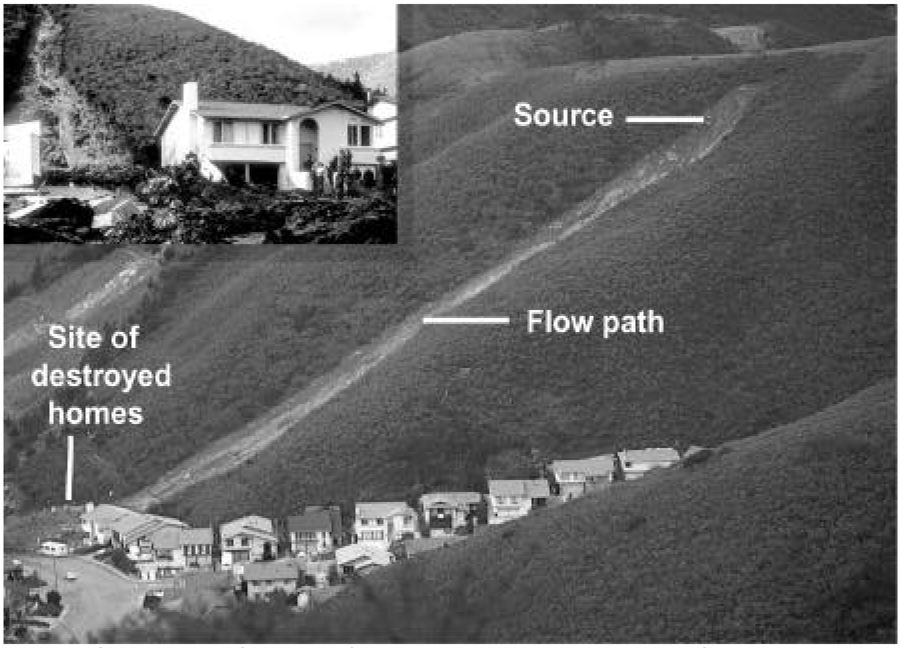
active landslides using state-of-the-art research and telecommunications technologies is critically needed nationwide in cases of imminent risk.

The following actions would 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, rainfall and pore-pressure monitoring integrated 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.

4. **Loss Assessment: Compiling and evaluating information on the economic impacts of landslide hazards, led by FEMA and 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 gauge the cost-effectiveness of policy decisions and effectiveness of mitigation measures. Loss data is critically needed to help government agencies identify trends and track progress in reducing losses from landslides.

   The following actions would 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.



Debris flow in Pacifica, California, about 10 miles south of San Francisco, where three children were killed and two homes destroyed on January 4, 1982. From USGS Fact Sheet 112-95. Photograph by Gerald Weizorek.

Warning of Potential Landslides

An experimental monitoring and warning system was developed and operated jointly by the USGS and the National Weather Service (NWS) from the 1980s to 1995 in the San Francisco Bay Region. The system used NWS protocols and outlets for issuing warnings, and 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 based on 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 NEXRAD and other precipitation data and forecasts provided by 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.

- 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.

5. **Information Collection, Interpretation, Dissemination, and Archiving: Establishing an effective system for Information Transfer, led by USGS and State geological surveys.** Collecting and disseminating landslide hazards information to Federal, State and local government agencies, nongovernmental organizations, planners, policy makers private citizens in a form useful for planning and decision-making is critically important to an effective mitigation program. Although landslide hazards have been studied for decades, systematic collection and distribution of 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 collection, interpretation, and dissemination of landslide hazard maps, assessments, and other scientific and landslide hazard technical information.

   The following objectives will make available landslide hazard information in a form useful to scientists, officials, decision-makers, 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.

6. **Guidelines and Training: Developing guidelines and training for scientists, engineers, and decisionmakers, led by USGS and professional societies.** The science 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 development of landslide maps and assessments. Hazard assessments involve assumptions and

Hazard zones from lahars, lava flows, and pyroclastic flows from Mount Rainier (USGS Open-File Report 98-428 by Hoblitt and others, 1998)

Alerting the Public to the Hazards of Mount Rainier

Mount Rainier in Washington is an active volcano that is currently at rest between eruptions. Its next eruption may produce volcanic ash, lava flows, or pyroclastic flows. 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 non-eruptive times when a section of the volcano collapses.

Lahars look and behave like rapidly flowing concrete, and their impact can destroy most man-made structures. Historically at Mount Rainier, they have traveled 45-50 miles/hr with thicknesses of 100 feet or more in confined valleys, slowing and thinning as they flowed into wider valleys that are now populated. At Mount Rainier, lahars are a greater hazard than other volcanic hazards such as lava and poisonous gases.

The likely courses of lahars will be the river valleys that drain Mount Rainier. Four of the five major river systems flow westward into suburban areas of Pierce County. The USGS 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 USGS Fact Sheet 065-97 "Mount Rainer—Living with Perilous Beauty" by K.M. Scott, E.W. Wolfe, and C.L Driedger.*

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 decision-makers are critically important to effective mitigation. Likewise, development of guidelines and training for planners and other decision-makers in the use of these maps and assessments is 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 decision-makers in the use of landslide hazard maps, assessments, and other technical information for planning, preparedness, and mitigation.

7. **Public Awareness and Education: Developing information and education programs for the user community, led by FEMA and 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 how to carry 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 would 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.

Earthflow in Cincinnati, Ohio. Material being removed by highway crew.

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 adjoining States of Kentucky and Indiana since before the 1850's, but the damage caused by landslides became increasingly expensive as urban development encroached more and more on the area's hillsides. The City of Cincinnati spent an average of about $550,000 per year on emergency street repairs for damage due to landslides between 1983 and 1987.

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 PublicWorks. The office, which is staffed by a geotechnical engineer, and 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, inspection of retaining walls that impact public right-of-way, review of 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 Ohio Department of Natural Resouces "Geofacts," no. 8, by Michael C. Hansen, September 1995 and USGS Bulletin 2059-A "Overview of Landslide Problems, Research, and Mitigation, Cincinnati, Ohio, Area" by Rex L. Baum and Arvid M. Johnson, 1996.

- 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.

8. **Implementation of Loss Reduction Measures: Encouraging mitigation action, 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, private financial and insurance incentives and disincentives, and other methods. The following actions would 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, 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.

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, CA, were condemned because of continued landsliding along Westline Drive. The homes were deemed permanently uninhabitable, and the city had no choice but to get the people out of imminent danger. By May, all residents had moved.

The Westline Drive landslide first grabbed 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 resulting in Westline Drive dropping as much as four feet at certain locations.

The recent 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 on the effected 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 with up to 8 inches beneath the pavement.

Assisting the homeowners will be a challenge. No insurance is available. The Federal Emergency Management Agency offered to buy the homes, but funds will only cover a part of the previous value of the homes. The Federal Small Business Administration offered mortgage loans at 4%, but for a reduced value of the homes and the homeowners must pay off their existing mortgages. Daly City and San Mateo County plan to supplement the Federal government's $6.5 million offer of assistance with housing funds totaling $1 million. If the city is successful, it will 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, USGS. Photograph of Daly City in 1998, by S. Ellen, USGS.

9. **Emergency Preparedness, Response, and Recovery: Building resilient communities, 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 would 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.

3. Action Items for a National Strategy for Reducing Losses from Landslides

3.1. Key Steps for Implementation

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

- 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.

3.2. Management Plan

Durable and effective solutions to the Nation's ground-failure hazards problems will require a continuing dialogue 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 decision making to accommodate the multi-jurisdictional, cooperative nature of the Program. An effective management plan would include the following:

- Establish coordination of the National Landslide Hazards Mitigation Strategy under the leadership of the USGS, because of its expertise and experience in landslide hazards research, monitoring, mapping, 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.

3.3. New and Enhanced Roles and Partnerships

Many different Federal, State, and local agencies, academia, as well as private companies, are involved in landslide research and mitigation in the United States (see **Appendix F** 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 coordination among 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 differing 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 U.S.</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>
</table>

Table 1 (continued). 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>5) Information Collection, Interpretation, Dissemination, and Archiving: Establishing an effective system for information transfer.</td><td>No systematic collection and distribution of landslide hazards information nationwide.</td><td colspan="2">Develop robust landslide hazards information clearinghouse system for the systematic collection, interpretation, archiving and distribution of scientific and technical information, databases, and maps.</td><td colspan="2">Collect and distribute needed information to decisionmakers.</td><td>Develop and share information.</td></tr>
<tr><td rowspan="2">6) Guidelines and Training: Developing guidelines, training for scientists, engineers, and decision makers.</td><td rowspan="2">Critical need for guidelines and training for scientists, engineers, planners and decision makers.</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 for the user community.</td><td>Little public awareness and understanding of landslide hazards, impacts on communities, and 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 programs, 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 landslide hazards 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="2">Adopt and implement policies and practices that support landslide hazards mitigation.</td><td></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>

3.4. 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) involves four principal tasks described below which would require expansion of the Program and additional funding. The USGS Landslide Hazard Program is currently funded for $2.2 million in FY 2000.

3.4.1. Expansion of 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 National Strategy. Approximately $8 million in new funding would be required to support:

- Additional research on landslide processes and triggering mechanisms (Element 1, pg 11) ($1.5 million).
- Additional hazard maps and assessments of landslide susceptible areas including developing standards and guidelines (Element 2, pg 13) ($2 million).
- Additional monitoring of active landslides and improvement of state-of-the-art research and telecommunications technology (Element 3, pg 13-15) ($2 million).
- Improved information collection, interpretation, dissemination, and technology transfer including public awareness and education (Elements 5 and 7, pg 17 & 19) ($1 million).
- Expanded emergency response and recovery capability and activities (Element 9, pg 23) ($1 million).
- Coordination of National Landslide Hazard Mitigation Strategy (Management Plan Section 3.2, pg 24) ($0.5 million).

3.4.2. Establishment of new Cooperative Landslide Hazard Assessment and Mapping Program

Establish a new cooperative program administered by the USGS Landslide Hazards Program to encourage understanding and mitigation of landslide and other ground-failure hazards by States, Territories, Counties and other local jurisdictions.

The primary goal of this program would be to reduce losses by increasing the availability of assessments and maps of landslide- and other ground-failure prone areas in the United States at a scale necessary to implement hazard loss reduction policies. This program will address all elements of the National Strategy, with a primary focus on element 2, landslide hazard mapping and assessments. USGS would provide guidance to encourage standardized assessment and map products that will be available digitally.

Priorities would be determined annually in consultation with State and Territory representatives. Grants to States and Territories would be awarded competitively. States and Territories would determine their priorities and sizes of grants to be distributed to their local jurisdictions in consultation with State- and Territory-wide advisory committees.

Approximately $8.0 million would be required to support competitive grants to the States, Territories and local jurisdictions each year. Each grant would be matched by a 30% State or Territory contribution, in order 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 would participate in such a program resulting in grants of varying sizes with an average grant of about $150,000 per State or Territory.

3.4.3. Establishment of new Cooperative Federal Land Management Landslide Hazard Program

Establish a new program administered by the USGS Landslide Hazards Program 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 would 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 program would 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 would be determined annually in consultation with representatives of Federal land management agencies.

Approximately $2.0 million would be required for scientific and technical assistance for Federal land management agencies. It is anticipated that the program will support approximately 20 agreements of varying sizes averaging about $100,000 each. It is anticipated that most of these funds would go to supporting hazard assessments, and monitoring equipment with USGS staff providing the technical assistance.

3.4.4. Establishment of new Partnerships for Landslide Hazard Loss Reduction Program

Establish a new competitive external grants program administered by the USGS landslide Hazards Program for research and application of research. The program would foster partnerships with universities, private consulting firms, professional associations, Federally Recognized Indian Tribal Governments, States and Territories, and local agencies.

This program would address all elements of the Strategy, with a primary focus on landslide hazard research and development and application of mitigation measures (elements 1, 2, 8).

Priorities for research and application of research would be determined annually in consultation with Federal, State, Territory, local, and private representatives.

Approximately $2.0 million would 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 would support approximately 25 agreements of varying sizes averaging about $80,000 each.

Funding Summary:

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

- 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 State and local governments efforts to map and assess landslide hazards within their jurisdictions through competitive grants ($8 million annually to be augmented with 30% matching funds by the States and local jurisdictions)
- Establishment of a Cooperative Federal Land Management Landslide Hazard Program to increase the National Park Service, U.S. Forest Service, Bureau of Land Management, and other such organizations capabilities 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)

3.5. Major Accomplishments and Products

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

- 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, decision makers;
- 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 (pg 15), compilation and evaluation of losses from landslide hazards.

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Appendix A. Meetings with Stakeholders

Meetings were held during 1999 and 2000 with representatives of stakeholder organizations that have important roles in reducing landslide losses in the U.S. in order to obtain their input into a national strategy to mitigate landslide hazards. Meetings were held with 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 National Strategy either through input at meetings or subsequent reviews of this report. The following are lists of participants who attended each meeting.

Landslide Hazards Mitigation Stakeholder Meeting
State Geologists Meeting
Philadelphia, PA
January 16-17, 1999

Lee Allison	State Geologist	Kansas Geological Survey
John Beaulieu	State Geologist	Oregon Department 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	USGS	Golden, Colorado
Lynn Highland	USGS	Golden, Colorado
John Filson	USGS	Reston, Virginia

Landslide Hazards Mitigation Stakeholders Meeting
Private Sector Meeting
Albuquerque, New Mexico
February 23-24, 1999

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	USGS, Golden, Colorado
Randy Updike	USGS, Golden, Colorado

Landslide Hazards Mitigation Stakeholder Meeting
Academic Sector Meeting
Albuquerque, New Mexico
February 26-27, 1999

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	USGS, Golden, Colorado
Randy Updike	USGS, Golden, Colorado

Landslide Hazards Mitigation Strategy Summit Meeting

San Antonio, Texas
August 31 – September 1, 1999

David Applegate	American Geological Institute
Rex Baum	USGS, Golden, Colorado
Steven R. Bohlen	USGS, Reston, Virginia
Bruce Clark	Leighton & Associates
Timothy Cohn	USGS, 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	USGS, Reston, Virginia
John Grant	NASA
Robert Hamilton	National Research Council
Lynn Highland	USGS, Golden, Colorado
G.P. Jayaprakash	NRC Transportation Research Board
Arvid Johnson	Purdue University
Jeff Keaton	AGRA Earth & Environmental, Inc., Phoenix, Arizona
Pat Leahy	USGS, Reston, Virginia
Lindsay McClelland	National Park Service
Doug Morton	USGS, Riverside, Calirornia
Robert Olshansky	University of Illinois, Urbana/Champaign
John Pallister	USGS, Reston, Virginia
William Roberds	Golder Associates, Redmond, Washington
William Shilts	Illinois State Geological Survey
Elliott Spiker	USGS, Reston, Virginia
Randy Updike	USGS, Golden, Colorado
Erik Van Marcke	Princeton University
Tom Yorke	USGS, Reston, Virginia

Landslide Hazards Mitigation Stakeholders Meeting
Land-Use Planners Meeting
Chicago, Illinois
February 17-18, 2000

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

Appendix B.
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. These studies and reports should be referred to for more in-depth discussions of and insights into landslide hazard mitigation and research needs:

- Goals, Strategies, Priorities and Tasks of a National Landslide Hazard Loss Reduction Program, (USGS, 1981, Open-File Report 81-987) sets forth goals and tasks for landslide studies, evaluating and mapping the hazard, disseminating information, and evaluating the use of the information.
- Goals and Tasks of the Landslide Part of a Ground-Failure Hazards Reduction Program, (USGS Circular 880, 1982) describes a national program.
- Feasibility of a Nationwide Program for the Identification and Delineation of Hazards from Mud flows and Other Landslides, (Campbell, Russell H et al, 1985, USGS Open-File Report 85-276) identifies the need for a national program.
- Reducing Losses from Landsliding in the United States, (Committee on Ground Failure Hazards, NRC, 1985, National Academy Press) recommends development of a national program and summarized the roles of government and the private sector in landslide mitigation nationwide.
- Landslide Classification for Identification of Mud Flows and other Landslides, (Campbell, Russell H., et al, Chapter A in USGS Open File-Report 85-276, 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, NRC, 1996, National Academy Press) provides a summary of the state-of-the-science of landslide hazard research, mapping and assessment in the U.S.
- National Mitigation Strategy – Partnerships for Building Safer Communities, (FEMA, 1996), provides a framework for mitigation of all natural hazards in the U.S.
- The Impacts of Natural Disasters – A Framework for Loss Estimation, (Board on Natural Disasters, NRC, 1999, National Academy Press) recommends compilation of a comprehensive database on losses of natural disasters.
- Land Subsidence in the United States, (Galloway, D., Jones, D.R., and Ingebritsen, S.E., eds., 1999, USGS Circular 1182) 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, Dennis S. Mileti, 1999, Joseph Henry Press) provides an overview about what is known about managing natural hazard disasters, recovery and mitigation.

Appendix C.
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, and changes in groundwater level, or seismic or volcanic activity. Long term climate change may result in an increase in precipitation and ground saturation and a rise in goundwater level, reducing the shear strength and increasing the weight of the soil. Erosion may 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 groundwater levels. Changes in irrigation, runoff and drainage can increase erosion and change groundwater 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 *Special Report 176: Landslides: Analysis and Control* (R.L. Schuster and R.J. Krizek, eds.), TRB National Research Council, Washington, D.C., pp. 12-13.).

Falls - abrupt movements of materials that become detached from steep slopes or cliffs, moving by free-fall, bouncing, and rolling, including:

> **Topple -** a block of rock that tilts or rotates forward and falling, bouncing or rolling down the slope.
>
> **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 if conditions are right.

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 earthquake.

Flows - Many types of mass movement are included in the general term "flow", including:

> **Creep -** the slow, steady down slope movement of soil or rock, often indicated by curved tree trunks, bent fences or retaining walls, tilted poles or fences.
>
> **Debris flow -** a 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.
>
> **Debris avalanche -** a variety of very rapid to extremely rapid debris flow.
>
> **Mudflow** – a rapidly flowing mass of wet material that contains at least 50 percent sand-, silt-, and clay-sized particles.
>
> **Lahar -** a 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 by the breakout of water from glaciers, crater lakes, or lakes dammed by volcanic eruptions.

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 may 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.

Subsidence - Another major form of ground failure, land subsidence, affects more than 17,000 square miles in 45 States. Land subsidence, a gradual settling or subsidence of the earth's surface, is an often-overlooked environmental consequence of land- and water-use practices. More than 80% of the identified subsidence in the Nation is a consequence of ground water withdrawal, and the increasing development of land and water resources threaten to exacerbate existing land subsidence problems and initiate new ones (Land Subsidence in the United States, U.S. Geological Survey Circular 1182, 1999, edited by D. Galloway, D. R. Jones, and S.E. Ingebritsen).

Swelling Soils – Another major form of ground failure, the swelling or rising of the ground surface, is a phenomenon frequently encountered in arid regions in soil containing montmorillonite clay. Montmorillonite clay particles can absorb large quantities of water, and in so doing will expand resulting in an uplift at the ground surface. Soils are usually not homogeneous, resulting in differential absorption and differential movements over a site. If the presence of the clay is unknown before development, the swelling may develop after a house is completed and residents begin watering gardens or using septic tanks, resulting in damage to structures and breaks in connecting utilities.

Permafrost – Ground failure related to frost action and permafrost are a problem in northern climates, especially in Alaska. Changes in climate and a significant warming in Alaska is resulting in widespread thawing of permafrost, often resulting in a settling of the soil.

Appendix D.
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 development can reduce losses by avoiding the hazards or by reducing the damage potential. Landslide risk can be reduced by 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 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 means of 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 landslides (NRC Committee on Ground Failure Hazards 1985).

***Codes for Excavation, Construction, and Grading Codes* -** Excavation, construction, and grading codes have been developed for construction in landslide-prone areas. There is no nationwide uniform code to ensure standardization in the United States; 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 (NRC Committee on Ground Failure Hazards, 1985).

***Protecting Existing Development* -** Control of surface water and groundwater drainage is the most widely used and generally the most successful slope-stabilization method (Committee on Ground Failure Hazards 1985). 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.

***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 NOAA 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 gauges, and National Weather Service precipitation forecasts.

***Landslide insurance and compensation for losses* -** Landslide insurance would be 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 (FEMA).

The primary reason insurance companies, for the most part, do not offer landslide insurance is the potential for adverse selection by the insured population. If insurance for landslides was made available, only those individuals in the most hazardous areas would buy the insurance, which would lead to very high premiums nearly equal to the value of the property. An alternative to private sector insurance would be 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-preventative 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 FEMA examined the feasibility of a nationwide program for identification and delineation of hazards from mud flows and other landslides. That study concluded that landslide hazards could be evaluated and mapped nationwide through a systematic sequence of studies, ranging from regional to local studies 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 E.
Landslide Hazards Maps and Risk Assessments

Public and private organizations need both sound economic and scientific basis for making decisions about reducing landslide-related losses. Quantitative risk assessment is a widely used tool for making such decisions as it provides estimates of the probable costs of losses and provides 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 an analysis of all possible consequences (property damage, casualties, and loss of service). Typically private consultants with expertise in risk assessment, in cooperation with the 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. An example would be a partnership in which the USGS and the State geological surveys cooperate to collect the basic geologic map data, and landslide inventory data. Local governments would provide access to their detailed topographic databases and records of landslide occurrence. 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 the 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.

Types of landslide hazards maps:

A **landslide inventory map** 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.

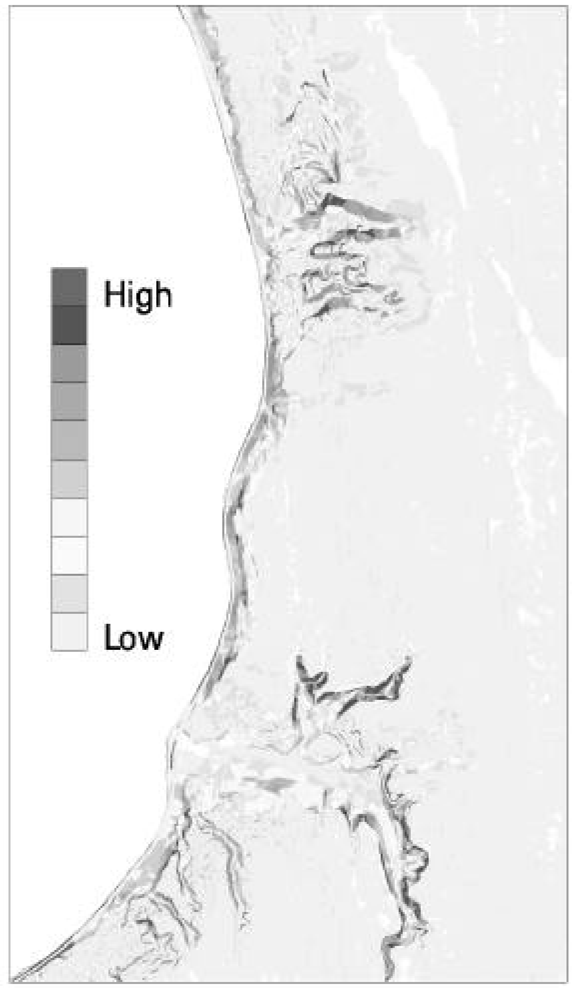
A **landslide susceptibility map** ranks slope stability of an area into categories that range from stable to unstable. Susceptibility maps show where landslides may form. Many susceptibility maps use a color scheme that relates warm colors (red, orange, and yellow) to unstable and marginally unstable areas and cool colors (blue and green) to more stable areas.

A **landslide hazard map** 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** 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. Landslide inventory map.

B. Landslide susceptibility map.



Maps showing initial steps of a regional landslide risk assessment for an area in Seattle, Washington. ***Figure A.*** *Landslide inventory map overlain on a topographic base map, showing the locations and outlines of landslides (USGS and Shannon and Wilson, Inc.).* ***Figure B.*** *Landslide susceptibility map (USGS, Colorado School of Mines).*

Appendix F.
Federal, State, and Local Agencies and Programs

Many different Federal, State, and local agencies, academia, as well as private companies, are involved in landslide research and mitigation in the United States; however, currently there is little interagency coordination of landslide hazard mitigation activities. Because the need for information spans the interests of many public and private organizations, the National Landslide Hazards Mitigation Strategy offers new opportunities for mutually advantageous partnerships relating to hazard assessments, monitoring, and emergency response and recovery. 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 that created the USGS. More recent legislation addressing the Federal role in landslide hazards include 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 (NSF) and the NASA fund landslide hazard research in the academic community. The National Oceanic and Atmospheric Administration, National Weather Service (NWS) personnel provide weather forecasts and assist in emergency response activities. Other Federal agencies, including the U.S. Army Corps of Engineers, Bureau of Land Management, U.S. Forest Service, National Park Service, Office of Surface Mining Reclamation and Enforcement, Department of Transportation (especially Federal Highway Administration), and Bureau of Reclamation have landslide hazard experts and activities in relation 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 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 to issue warnings of imminent landslides and manage emergency operations after a landslide. FEMA may become involved after a Presidential 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 conduct research on landslide processes and 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.

Federal Agency Landslide Hazards Activities

The following Federal agencies provided descriptions of their landslide hazards activities.

Department of the Interior - U. S. Geological Survey

The USGS directly or indirectly funds and maintains landslide hazard expertise in several of its programs. These programs direct research and assessment of landslides, debris flows, and lahars caused by storms, earthquakes and volcanoes, submarine landslides, riverine and coastal erosion. The following is an explanation of USGS landslide hazard activities:

Landslide Hazards Program - The Landslide Hazards Program supports hazard investigations and assessments, research on monitoring and forecasting landslides, responding to landslide emergencies and operating the National Landslide Information Center in Golden, Colorado. The Program supports research and assessment that can lead to implementation of mitigation strategies for Federal, State, and local land-management and emergency-response agencies, as well as providing 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 East.

The program supports research on landslide processes and development and deployment of instrumentation to monitor active landslides to improve landslide forecasting. The majority of the real-time monitoring activities are taking place in Washington, California, New Mexico, and Colorado. The Program also responds, on request, to national and international landslide disasters. In this capacity, the Program assists Federal, State, and local agencies to evaluate landslide hazards and recommends mitigation strategies.

The National Landslide Information Center maintains landslide databases, communicates with the public and press about ongoing landslide emergencies, and provides information to the public and organizations through fact sheets, a dedicated Internet website (http://landslides.usgs.gov), books and reports.

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 U.S.

Water Resources Division Programs - The Water Resources Division conducts research on landslides, debris flows, subsidence, and riverine and coastal erosion. Research is also supported through its District Offices in Hawaii, Puerto Rico, and other States as landslides occur.

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 assistance, and promotion of landslide hazard mitigation.

FEMA coordinates the Federal government's response to disasters such as earthquakes, hurricanes, and volcanoes 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, rock toes, etc. 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 damaged by mudslides who are covered by 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 FEMA's Project Impact, the agency is encouraging local jurisdictions to implement mitigation programs that reduce among other hazards, landslides. In the Seattle Project Impact, landslide hazard mapping is a major part of the community's effort.

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 impact parks by 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, such as through 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 as they work to provide safe public access to popular but potentially hazardous areas. When a landslide or other hazard occurs, parks must quickly rescue people, stabilize structures, and clear debris from roads and other public areas. Critical next steps are to work with experts to assess the nature and extent of the event and the risk and recurrence. Short-term studies are required to help managers decide whether and when to reopen impacted areas, then more detailed research is often needed to inform 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, offering the opportunity to help 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 the content of exhibits in visitor centers, and in some cases through books and videos sold by park 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 including school programs and websites. 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 non-specialists.

These and other park programs would 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.

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

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. Office of Surface Mining, through its Federal Reclamation Program has responsibility in those State/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/Tribes have completed reclamation on 3,367 acres of dangerous slides at a cost of $125.25 million. Also, 651 acres are designated as a 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.

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 system lands are located in the mountainous areas of the western United States including large parts of Alaska. The road system on National Forests is of a comparable size to many State road systems. As a consequence, designing low volume roads to avoid landslide problems and repairing the damage to them from landslides is a major task. Additionally, the location of National Forests means Interstate and major State highways, railroad lines, oil and gas pipelines, and electric transmission corridors pass through them. It is necessary to address landslide hazards in the environmental assessment of these projects and where specific landslide impacts occur along existing ones.

National Forests generally occupy the headwaters of major rivers, which places a premium on watershed management. This is especially true for those watersheds where anadromous fisheries and significant inland fisheries are present. Increased landslide activity can produce sediment loads that degrade water quality and impact 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 take place. Major wildfires may sufficiently denude watershed and lead to short-term landslide activity. National forests, especially those having developed private in-holdings and adjacent urban areas, must address the potential for loss of life and damage from debris flows initiated by precipitation events on burned watersheds.

A primary landslide hazard activity conducted by Forest Service personnel is providing evaluations of landslide hazard potential in environmental assessments or in review of 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 this damage.

A national geographic information system network of National Forest lands and a data base that includes landslide information is under development. Both existing USGS and State survey information and mapping by Forest Service geologists generate the landslide hazard information for this GIS system. The Research Branch of the Forest Service has contributed many studies that improve our understanding of landslide hazard relative to specific forest management activities.

Department of Commerce – National Oceanic and Atmospheric Administration

The National Oceanic and Atmospheric Administration, 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. 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.

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

As the premier full spectrum engineering organization, the missions of the Corps of Engineers include 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, Air Force, and other federal agencies. In performance of 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 which result in serious navigation hazards and threatening 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 the monitoring of active landslides and ground failure in both natural and engineered soils and earth materials. Monitoring of landslides have focused on the identification of the temporal and spatial variability of earth movements and the identification of causal factors. Monitoring data have been used along with detailed site information to analyze the stability of the landslide in terms of the 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' critical and efficient flow of responsibility and results in landslide projects through the process of initial engineering geological investigation, engineering analysis, remedial design, implementation, construction, and post project 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 as a result of 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 also become a major focus of 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 Phillipines.

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.