The U.S. Geological Survey
Landslide Hazards Program 5-Year Plan
2006-2010

U.S. Department of the Interior
U.S. Geological Survey

Contents

National Landslide Hazards Program
5-Year Plan
FY 2005-2010

Executive Summary

Landslides are a national problem as they occur in significant numbers throughout the United States. The most significant landslide problems occur on the Pacific Coast, and in the Rocky Mountains, the Appalachian Mountains, Hawaii and Puerto Rico. It is estimated that landslide-related fatalities average from 25 to 50 per year, and direct and indirect economic costs to the nation range up to $3 billion per year. The costs of landslides are increasing rapidly as lands susceptible to failure are developed for highways, housing, industry, and recreation. USGS landslide hazards investigations focus on landslides that occur in association with other natural disasters such as earthquakes, volcanic eruptions, floods and heavy rains, hurricanes, and wildfires.

The Landslide Hazards Program (LHP) and its predecessor have operated since the mid 1970's as a Congressionally-authorized program dedicated to the reduction of damages and avoidance of hazards from the different forms of landslides. The focus of the program is national, but it also responds to requests for assistance in foreign countries from the Department of State, as well as from international organizations such as the World Bank and the United Nations. As the only Federal program dedicated to landslide hazards, the LHP provides results of investigations for use by private consultants in geology and geotechnical engineering and by planners and decision makers at all levels of government and in the private sector. The results of LHP efforts have led to significant improvements in understanding the nature and scope of landslide problems nationally and worldwide. Such improvements are central to the success of the Program, but opportunities remain for fundamental advances in understanding that promise to save lives and dollars nationwide.

Statutory authority for the LHP is found in the Organic Act of March 3, 1879, and the Disaster Relief Act of 1974. The Disaster Relief Act of 1974, Section 202(a), also known as the Stafford Act, gives the USGS the responsibility to issue timely disaster warnings of potential landslides.

In 1999, the U.S. Congress directed the USGS to develop a comprehensive strategy to address the widespread landslide hazards facing the Nation in response to concern that landslide hazards were not being adequately addressed. The LHP's 5-year plan (2005-2010) incorporates the recommendations outlined in this comprehensive strategy contained in the USGS Circular 1244, "National Landslide Hazard Mitigation Strategy" (Spiker and Gori, 2003) and recommendations from the National Research Council of the National Academy of Sciences' review of the strategy entitled, "Partnerships for Reducing Landslide Risk," (National Research Council, 2003).

The LHP supports the USGS mission to "serve the Nation by providing reliable scientific information to minimize loss of life and property from natural disasters." The LHP's mission is to provide information that leads to the reduction of losses from landslides and increase in public safety through improved understanding of landslide hazards and strategies for hazard mitigation. In pursuit of the program mission, the LHP conducts landslide hazard assessments, pursues landslide investigations and forecasts, provides technical assistance to respond to landslide emergencies, and engages in outreach activities.

Research on landslide hazards addresses fundamental questions of where and when landslides are likely to occur; the size, speed, and effects of landslides; and how to avoid or mitigate those effects. Such research is essential if the LHP is to make significant progress in addressing landslide problems triggered by severe storms, earthquakes, volcanic activity, coastal wave attack, and wildland fires in the United States. Public and private decision makers increasingly depend on information that the LHP provides before, during, and after a disaster so that they can live, work, and build safely.

The LHP works closely with states, other bureaus within the Department of the Interior, and other Federal and State agencies to reduce landslide losses. The LHP anticipates working closely with Oregon, California, Hawaii and other states during the next 5 years. LHP is working with the National Oceanic and Atmospheric Administration (NOAA) on a new landslide hazard alert system. LHP also has a partnership with the American Planning Association on an effort to incorporate landslide hazards information into the land-use planning process. LHP is a member of the International Consortium of Landslides, a United Nations sponsored organization, which among other activities, is producing a universal handbook on understanding landslides and landslide mitigation.

Fulfilling the mission of the LHP--to provide information that leads to the reduction of losses from landslides and increase public safety through improved understanding of landslide hazards--requires developing the information, scientific understanding and capabilities needed to issue accurate warnings, advisories, or notifications of landslide hazards. Each of the program's 5-year goals combines a balanced mix of applications and research to achieve their mission. The following are the Program's long-term goals: 1) Conduct landslide hazard assessments, 2) Monitor and model active landslides, 3) Provide pre- and post-landslide hazard event assessments, and 4) Provide landslide hazard information and studies of landslide hazard mitigation.

The LHP updates its 5-year plan every 5 years or more frequently if necessary. Revision of the program's 5-year plan is led by the program coordinator with input from project chiefs, team chief scientists, and landslide experts representing from each of the following: State geological surveys, universities, and private industry. The final plan is reviewed within the USGS and externally. In 2003 the National Research Council (NRC) of the National Academy of Science completed a review of the National Landslide Mitigation Strategy proposed by the LHP at the request of Congress, and it

commended the USGS for undertaking the important initial steps toward implementing a comprehensive national landslide hazards mitigation strategy and recommended increased funding for the LHP.

As of 2005, the LHP has a scientific staff consisting of 17 geologists, engineers, hydrologists, physical scientists, geographers, and land-use planners who have expertise in a broad range of landslide types and processes. LHP scientists have experience in applying field, experimental, and theoretical techniques to landslide research, real-time monitoring, and hazard assessments. LHP anticipates several retirements before 2010, and the LHP will need to hire additional staff to maintain the necessary expertise to continue its leadership in landslide hazards research, monitoring, and assessments.

Introduction

Program History

Landslides are a national problem. They occur in significant numbers in all 50 States and the territories. The most significant landslide problems occur on the Pacific Coast, and in the Rocky Mountains, the Appalachian Mountains, and Puerto Rico. It is estimated that landslide-related fatalities average from 25 to 50 per year and direct and indirect economic costs to the nation range up to $3 billion per year. Globally, landslides cause billions of dollars in damages and thousands of deaths and injuries each year. The costs of landslides are increasing rapidly as lands susceptible to failure are developed for highways and other infrastructure facilities and for urban and suburban housing, industry, and recreation. USGS landslide hazards investigations focus on the urban environment and on landslides that occur in association with other natural disasters such as earthquakes, volcanic eruptions, floods, hurricanes, and wildfires.

The Landslide Hazards Program (LHP) and its predecessor have operated since the mid-1970's as a Congressionally authorized program dedicated to the reduction of damages and avoidance of hazards from different forms of landslides. The focus of the Program is national, but it also responds to requests for assistance in foreign countries from the Department of State, as well as through international organizations such as the World Bank and the United Nations. Principal activities of the LHP include conducting research and monitoring active landslides, responding to landslide emergencies and disasters, and producing scientific reports, and maps, and other products for a broadly based user community. As the only Federal program dedicated to landslide hazards, the LHP provides results of investigations for use by private consultants in geology and geotechnical engineering and by planners and decision makers from all levels of government and the private sector. The results of these efforts have led to significant improvements in understanding the nature and scope of landslide problems nationally and worldwide. Such improvements are central to the success of the Program, but opportunities remain for fundamental advances in understanding that promise to save lives and dollars nationwide.

Landslide investigations began in the United States at the end of the nineteenth century. The first comprehensive USGS study of landslides was an examination of landslides in the San Juan Mountains of southwestern Colorado. The study identified a region with a significant landslide distribution although it did not assess landslide hazard and risk. In the late 1940's, the USGS with the National Park Service (NPS) and the US Bureau of Reclamation conducted a statistical evaluation of slope stability around Franklin Roosevelt Lake, Washington, and prepared maps identifying landslides and potential landslide prone areas. This work was followed by cooperation in 1950 with the Corps of Engineers to produce landslide investigations of the Columbia River between Grand Coulee and Chief Joseph Dams. This investigation was one of the first comprehensive regional landslide studies resulting in a landslide

hazard assessment that included landslide inventory maps. In the 1970's, landslide inventory maps were developed in California, Pennsylvania, and Colorado. The Landslide Overview Map of the Contiguous United States by Radbruch-Hall and others in 1983 was digitized and reissued to include updated data and an additional overlay to show all U.S. counties. (See Godt, USGS Open File 97-0289 and Radbruch-Hall and others, USGS Professional Paper 1183). In 1997-1998, a digital version of the National Landslide Overview Map was combined with the National Oceanic and Atmospheric Administration's (NOAA) National Climate Outlook Maps to identify areas that might be susceptible to landslides during the wet, El Niño year. These maps were made available on the USGS and NOAA websites and updated quarterly.

To assess landslide hazards on a more local scale, inventory maps were produced for cities and authorized by the U.S. Congress in the Flood Control Act of 1966. LHP has continued to produce inventory maps and added the production of landslide susceptibility maps and hazard maps to provide a more up-to-date, detailed, and useful assessment of landslide hazards. Earl Brabb, who produced the first regional landslide-susceptibility map of San Mateo County, California in 1972, and others at the USGS were pioneers in landslide susceptibility mapping.

One of the most important advancements in knowledge was the classification of landslides by David Varnes, who developed a useful vocabulary of terms to describe landslides that is used by scientists, engineers and land-use planners throughout the world. Beginning in 1958, David Varnes classified slope movement types and processes in a National Research Council Special Report 29 (Varnes, 1958). The classification system was refined by Varnes and others in subsequent National Research Council Special Reports 176 (Schuster, and Krizek, 1978) and 247 (Turner and Schuster, 1996). Varnes' system of naming landslides first by their material then by the type of movement, such as rock fall and debris flow, has given landslide experts a common language. Other USGS scientists made significant contributions as authors and scientific editors on these special reports, which have become standard references for landslide investigation and mitigation in the U.S. and worldwide. In addition, USGS landslide researchers have authored hundreds of other technical papers that have contributed case studies of important landslides, expanded the understanding of landslide processes, and advanced the scientific and technological underpinnings of landslide investigation and mitigation. Examples include work on predicting catastrophic failure, the development of the Newmark method for modeling earthquake-induced landslides (now used extensively worldwide), and, more recently, the development and implementation of the first web-based, real-time monitoring of active landslides.

The concept for documenting rainfall duration and intensity associated with shallow landslides was initiated by Russell Campbell in the 1970's and refined by Susan Cannon, Stephenson Ellen, Gerald Wieczorek and others in the 1980's. Rainfall thresholds are essential for landslide warning systems that were operated by the USGS in the San Francisco Bay area from 1986 to 1995 and near-real time warning systems that are currently being operated throughout the US in cooperation with state

and local governments. Scientists have used the methodology that was originated by USGS scientists in the 1970's and 1980's to develop rainfall thresholds that have been used to issue landslide hazard warning during several events: the 2004-2005 winter storms in southern California; Hurricane Isabel in 2003; storms in Puget Sound, Washington in 2000 and 2003-2004; and the San Francisco Bay area 2003-2004 rainy season.

USGS landslide experts have led or participated in numerous international landslide hazard response efforts that are funded by the Agency for International Development, Office of Foreign Disaster Assistance and requested by countries impacted by the disasters.

Program Authorizations

Statutory authority for the Landslide Hazards Program is found in the Organic Act of March 3, 1879, and the Disaster Relief Act of 1974. The Organic Act of 1879, amended in 1962 and restated in annual appropriation acts, established the Geological Survey and directs it to classify the public lands and examine the geological structure, mineral resources, and products within and outside the national domain. The Disaster Relief Act of 1974, Section 202(a), also known as the Stafford Act, gives the USGS the responsibility to issue timely disaster warnings of potential landslides. Accordingly, the LHP's goal is to contribute to the reduction of casualties, property damage, and economic losses from landslides by providing a sound scientific basis for improved hazard assessment and mitigation strategies and by demonstrating the application of new knowledge and techniques to reduce landslide losses.

Current Scientific Accomplishments, Societal Needs, and National and Regional Priorities

The LHP is a relatively small program (17 scientists and managers) that has contributed beyond the numbers of its personnel to the science of ground failure and movement and to the practical application of that science in the public service. LHP provides relevant, objective, and credible information that addresses national landslide problems and forms the scientific basis for effective strategies to reduce hazard and risk from landslides and other related forms of ground failure. In pursuit of the program goal, the LHP conducts landslide hazard assessments, pursues landslide investigations and forecasts, provides technical assistance to respond to landslide emergencies, and engages in outreach activities.

The demands of modern society require new approaches to hazard issues. In response, the LHP has anticipated and systematically updated its priorities by addressing the landslide hazards in economically vital areas and by assessing landslide hazards triggered by natural disasters such as storms, snow melt, earthquakes, and volcanic eruptions. In addition, the LHP has assisted Federal land managers, State and local government agencies, and foreign governments to assess

and reduce specific landslide hazards. Some examples of how LHP information has been recently incorporated into local mitigation activities are as follows:

- Uinta National Forest, Idaho District of the Bureau of Land Management and San Bernardino County, California changed the way they maintain, use, and reconstruct existing debris-flow basins, campgrounds, and other recreational facilities.
- San Bernardino and San Diego Counties and San Bernardino National Forest in California and the Idaho State Highway Department used post fire debris-flow hazard maps for emergency response plans and warning systems.
- The City of Seattle, Washington, is using a landslide probability map compiled by LHP to set priorities for mitigation and planning redevelopment of hillside areas. The city has also begun using rainfall threshold information in its emergency preparedness planning.
- In March and April of 2005, LHP scientists assisted FEMA and the State of California officials in their recovery efforts for affected communities following the debris flows and other damaging landslides that occurred during the winter of 2004/2005 in southern California. The recommendations and expert advice given by the scientists resulted in well-informed public and private decisions on where and how to rebuild public and private buildings and infrastructure in the areas affected by the winter storms so that the structures would be less susceptible in the future.

Losses and risks associated with natural hazards can be reduced significantly if decision makers and individuals of all levels of government and the private sector take well-informed actions before a disaster occurs and respond appropriately after a disaster. Decision makers increasingly depend on information that the USGS provides before, during, and after a disaster so that they can live, work, and build safely. The USGS's ability to provide end users with critical landslide hazards information can be greatly improved by enhancing research and assessments and monitoring and developing new tools for interpreting, integrating, and communicating information related to these hazards.

The National Landslide Hazards Mitigation Strategy builds a foundation for increasing the national commitment to reduce landslide losses, including increased funds for hazard assessment, monitoring, research, and outreach by USGS and others by working with partners from State, Federal, and local governments and the private sector.

Future Initiatives and Scientific Directions

National Landslide Hazards Mitigation Strategy

In 1999 in response to growing national concern about landslide hazards, the U.S. Congress, through House Report 106-222 accompanying the Interior Appropriations

bill for Fiscal Year 2000, which was incorporated in Public Law 106-113, directed the USGS to develop a comprehensive strategy to address the widespread landslide hazards facing the Nation. The LHP's 5-year plan incorporates the recommendations contained in the comprehensive strategy as outlined in the USGS Circular 1244, "National Landslide Hazard Mitigation Strategy" (Spiker and Gori, 2003) and in the National Research Council (NRC) of the National Academy of Sciences' review of the strategy entitled, "Partnerships for Reducing Landslide Risk," (National Research Council, 2003).

The National Landslide Hazard Mitigation Strategy recommends that the USGS work in partnership with other Federal and State agencies to meet the challenges of the National Strategy. USGS proposes three principal tasks requiring aggressive pursuit as well as additional funding totaling $20 million annually initially and growing to $50 M annually: (Spiker and Gori, 2003 and NRC, 2003.)

- Expansion of the LHP to provide needed coordination, information management, and development of guidelines, training, and outreach capabilities.

- Expansion of the LHP to provide needed research, mapping, assessments, monitoring, and emergency response capabilities.

- Establishment of Federal-State public-private cooperative and grant programs to fund and encourage landslide hazard research, mapping, assessment, and mitigation efforts nationwide.

During 2005-2010, the LHP will publicize the National Landslide Hazards Mitigation Strategy and NRC report in order to gain approval of the concepts outlined in the Strategy and in order to obtain a consensus of Federal, State and local partners regarding the importance of implementing the Strategy. Recently, the LHP made presentations to many organizations including the American Association of State Geologists, the American Planning Association, and the National Earthquake Conference sponsored by the Western States Seismic Policy Council. In addition, numerous articles authored have been published in professional and trade journals about the importance of implementing the Strategy. The program is also an important feature of the USGS Fiscal Year 2007 Natural Hazards Initiative (see discussion below under Future Initiatives and Scientific Directions).

Fiscal Year 2007 Natural Hazards Initiative

At the request of the Director, the USGS has begun to develop a major new initiative focused on reducing the risks and impacts of selected natural hazards. The initiative will concentrate on an integrated approach for assessing natural hazards that cause sudden disasters such as earthquakes, hurricanes, wildfires, floods, volcanoes, and debris flows. The initiative is intended to enable the USGS to work with partners to develop understanding and approaches in order to increase societal and ecological

resiliency to disasters. As part of the initiative, LHP scientists prepared a comprehensive plan for expanding the LHP in accordance with the National Landslide Hazards Mitigation Strategy and National Research Council (NRC) recommendations. Debris flows, especially as they relate to fire, will probably be the major thrust of the initiative funding. Implementation of the 2007 Initiative will give the LHP the opportunity to make strides in implementing the Landslide Hazards Mitigation Strategy.

NOAA/USGS Debris-Flow Hazards Alert/Warning System

During FY 2005 and FY 2006, the LHP will pursue a new thrust, focusing on post-fire debris-flow hazard research and application of landslide forecasts. Burn severity information derived from Landsat and other satellite information will be provided by the USGS Land Remote Sensing and Geographic Analysis and Monitoring programs. While the initial target area will be southern California, other fire-prone areas of the West will be included in out-year studies. First, a decision support system will be designed to lead the fire-fighting community (USDAFS, CA OES, fire managers, restoration teams, and others) through varying procedures for the assessment of debris-flow hazards from recently burned basins. Second, a debris-flow hazards alert/warning system with a protocol developed jointly by USGS and the National Weather Service (NWS) (NOAA) with input from emergency managers and responders will be initiated in southern California. (See USGS/NWS Charter Appendix A)

Scientific Research

Research on landslide hazards addresses fundamental questions of where and when landslides are likely to occur; the size, speed, and effects of landslides; and how to avoid or mitigate those effects. Such research is essential if the LHP is to make significant progress in addressing landslide damage triggered by severe storms, earthquakes, volcanic activity, coastal wave attack, and wildland fires in the United States. Several of the future initiatives in this section, including the NOAA/USGS debris-flow alert system, and the 2007 USGS hazards initiative, discuss directions for future scientific research focused on many of these questions. Here we provide additional details on research that the LHP plans to undertake during the period from 2006 to 2010, whether or not any of the above initiatives are funded.

New predictive models

In recent years, the LHP has developed models for assessing relative slope stability or landslide susceptibility over a landscape. These tools can estimate the timing, location, and size of future landslides. One of these models (SCOOPS) can analyze the potential for 3-dimensional deep rotational failures on scales ranging from coastal bluffs to volcanic edifices. The program plans to enhance this model to analyze 3-D translational failures on similar scales. Because this model provides failure volumes, the LHP also plans to integrate it with the Volcano Hazard Program's models for predicting downslope inundation areas of landslides and debris flows.

Another USGS model (TRIGRS) analyzes time-dependent infiltration of rainfall and resulting slope instability of shallow colluvial deposits that slide and mobilize into debris flows. The LHP plans to enhance this model to analyze infiltration into initially unsaturated soil at the beginning of a storm and lateral flow that develops during long-duration rainfall. Research is also needed to represent results of various susceptibility models in probabilistic terms for use in static as well as next-generation dynamic maps of landslide susceptibility in response to real-time rainfall and/or seismic input. Continued research in landslide histories and recurrence is necessary to improve understanding of landslide probability in most parts of the U.S., including the examination of landslide events during heavy rainfall in the mountain regions of the Eastern US to refine the rainfall thresholds in that region. Also, improved capabilities in modeling and probability will be applied to landslide hazard assessments in other parts of the U.S.

The desire on the part of emergency managers and others for early warning of landslides makes continued development of rainfall and snowmelt thresholds for various landslide types throughout the U.S. a major priority for the LHP. In addition to development of historically based empirical thresholds, research is also planned to determine whether accurate rainfall thresholds can be developed rapidly using the deterministic model TRIGRS.

Debris flows and other landslides occurring in burned areas of the western U.S. are expected to be a continuing problem, and continued research is planned to improve existing drainage-basin scale models for estimating debris-flow probability and magnitude. Work is also planned to include these in a decision support system for rapid assessment of post fire debris-flow hazards. The LHP has acquired a significant database of post-fire debris flow response and processes, including the availability of national-level burn severity information derived from Landsat satellite imagery. Research is planned to advance from the existing empirical models to physically based models of runoff and erosion processes in burned areas. Such models are expected to lead to improved resolution and accuracy of post-fire debris flow assessments.

New landslide monitoring techniques

The LHP plans to improve and expand monitoring techniques in dynamic landslide environments. Such techniques will enable better prediction and forecasting of future activity. The program expects to expand ground-based, real-time monitoring capabilities to detect the transition from slow creep to rapid catastrophic failure using instruments such as arrays of low-cost GPS receivers. Advancements in landslide monitoring are also planned to improve understanding of antecedent conditions and storm-induced changes in surface and subsurface water. Such conditions control the occurrence and movement of debris flows (with accompanying sediment entrainment) and deep-seated landslides. As opportunity and resources allow, the program plans to research and apply Landsat data and high-resolution remotely sensed data, such as LIDAR and SAR, to detect, map, or rapidly assess landslides.

New insight into poorly understood landslide processes

The LHP plans focused research on the following particularly troublesome and poorly understood landslide hazards. The understanding gained will provide a framework for developing currently unavailable assessment tools.

- Field and analytical studies are planned to better understand the process of debris-flow enlargement. Many destructive debris flows appear to originate from very small source areas and expand through a "bulking" process by eroding their channels and entraining the sediment as they descend. Work to understand the mechanics and preconditions of debris-flow enlargement is needed to improve assessments of debris-flow hazard.

- Research to understand the conditions required to cause reactivation of landslide deposits is also needed to aid entities responsible for transportation, planning, utilities, and lifelines. Within a given geographic area, landslides occur under similar geographic, topographic, seismic, and climatic conditions, and those similarities are great enough that some predictive understanding can be gained by regional geotechnical and modeling studies (using tools such as SCOOPS or TRIGRS as well as Finite-Element analysis) of pre-existing landslides. Such understanding would aid in predicting the kinds and severity of actions likely to cause reactivation of old landslides. One of the areas where the LHP will focus its work is in Punta Gorda, Ventura County, California, an area that contains many different types and ages of landslides that were triggered during the winter of 2005.

- Frequent requests from other agencies for assistance with rock-fall problems will result in continued research and application of methods for assessing rock-fall hazard on public lands.

Partnerships with States, other Organizations, and other USGS Programs

Landslide Hazard Program anticipates working closely with Oregon, Hawaii, California, North Carolina, and other states on landslide issues particular to each State during the next 5 years. LHP will be completing a major, multi year effort in the Puget Sound area of Washington. It will apply some of the scientific findings from that effort to the western part of Oregon, commencing with Portland Hills. LHP will implement activities suggested in the National Landslide Hazard Mitigation Strategy by supporting the Oregon Department of Geology and Mineral Industries (DOGAMI) to improve the level of landslide hazard mitigation in Oregon. Similar, but less ambitious, efforts are planned in other States, including California, North Carolina, and Hawaii.

Landslide Hazard Program is planning a cooperative effort with the Centers for Disease Control and Prevention (CDC) to map landslide and others natural hazards in the Pacific Islands to reduce hazards and the loss of life and injury that commonly

occur during typhoons, earthquake, tsunamis, etc. that trigger landslides, flooding, and building collapse. LHP and CDC are proposing funding of a multi agency/national effort for a five- to ten-year project to assess hazards and prepare maps for island nations that are the most vulnerable to the various natural hazards.

NASA, NOAA, and the USGS have proposed a 3-year study that will include satellite (and other real-time) observations, atmospheric and hydrological models, landslide models, and a coastal surge model. Entitled, "Hurricane Flood-Landslide Continuum," this initiative seeks to close the gap between the scientific state of the art and the operational needs for reliable and timely information. A prototype study in Puerto Rico and Hispaniola, which have available data and high probability of hurricanes, will make it possible to demonstrate the relevance of such a system across a spectrum of technological and socioeconomic environments.

The LHP relies heavily on the analysis of elevation data in combination with other geospatial information. A close partnership with the Geography Discipline's elevation activities will help facilitate the efficiency of elevation data analysis and the development of new capabilities. Additionally, LHP anticipates working closely with the Land Remote Sensing and the Geographic Analysis and Monitoring Programs to develop use of Landsat and other satellite imagery for post-fire burn severity mapping, analysis of land cover change, and monitoring of dynamic landslide environments.

Educational activities and products

The USGS will work with the American Planning Association (APA) to encourage use of the handbook entitled, "Landslide Hazards and Planning." The handbook, which APA wrote for its membership with assistance and funding from USGS scientists and LHP, will be an important resource for land-use planners to use to address landslide issues in their communities.

The International Consortium of Landslides, the Geological Survey of Canada, and the U.S. Geological Survey Landslide Hazards Program will be writing, translating, and distributing a "universal" handbook that is designed for citizens to understand landslides and landslide mitigation. The project is expected to be accomplished in 3 years and will be funded by the three agencies involved. The draft that was completed in early 2005 will be ready for translations by 2006. It will also be available as an internet-based product.

Program Mission

The LHP supports the USGS mission to "serve the Nation by providing reliable scientific information to minimize loss of life and property from natural disasters. "The LHP's mission is to provide information that leads to the reduction of losses from landslides and an increase in public safety through improved understanding of landslide hazards and strategies for hazard mitigation.

The USGS, May 12, 2000 Strategic Plan (FY 2000-2005) identifies a long-term goal that relates to hazards, which is to:

"Ensure the continued transfer of data, risk assessments, and disaster scenarios needed by our customers before, during, and after natural disasters, and increase the delivery of real-time hazard information to minimize loss of life and property."

The LHP supports the U.S. Department of the Interior's Strategic Plan (Fiscal Year 2003-2008) through its strategic goal, "Safeguard lives, property, and assets, advance scientific knowledge, and improve the quality of life for communities we serve." Specifically the LHP supports Goal 1, "Protect lives, resources and property," through increasing the percent of communities using DOI science on hazard mitigation, preparedness, and avoidance. The LHP also supports the DOI goal, "Advance Scientific Knowledge." The end outcome measure for the LHP is "Percent of communities in the US using DOI science on hazard mitigation, preparedness, and avoidance for landslide reduction."

Program's 5-year goals objectives, and measures

Fulfilling the mission of the LHP to "serve the Nation by providing reliable scientific information to minimize loss of life and property from natural disasters" requires developing the information, scientific understanding, and capabilities needed to issue accurate warnings, advisories, and notifications of landslide hazard. Each of the program's 5-year goals combines a balanced mix of applications and research to achieve the above mission. The program's scientific goals are interdependent and interrelated and are aimed at reducing losses and improving public safety through reducing the uncertainty in the locations, timing, and magnitudes (size, speed, and travel distance) of future landslide events. The program's communication goal is aimed at informing decision makers and the general public about landslide hazards so that they can take actions needed to mitigate the hazards and then collecting information needed to improve the effectiveness of future communication in reducing landslide-related losses. The following are the program's long-term goals, with the outcome measures and partners identified for each goal. A table identifying the outcome measure and the projected year in which the outcome is attained follows this discussion.

Landslide Hazards Assessments

Conduct field studies, research, monitoring, and analyses directed at reducing landslide hazards and risk in the United States with special emphasis on developing new procedures and pilot studies for hazard assessments using GIS and remote-sensing techniques. Conduct studies to verify hazard assessments against inventories of subsequent landslide events. Improve accuracy of rainfall thresholds for predictive landslide measures during major storm events, especially in the Appalachians. In

cooperation with other Federal, State, and local agencies, and USGS Water Resources Discipline (WRD) science centers, develop regional data sets and tools (including landslide inventories, models, recurrence intervals, and relative or absolute landslide ages) for estimating landslide probability under rainfall, snowmelt, seismic, and post-wildfire conditions.

Develop models for estimating volumes of material that can be produced from recently burned basins in southern California as a function of basin morphology, material properties, burn severity, and storm rainfall. Develop models for estimating the probability of debris-flow production from basins recently burned by wildfire in southern California. Develop a Decision-Support System that will be used to assess post-wildfire debris flow hazards and direct mitigation approaches in recently burned basins in southern California. In collaboration with the State of Oregon, conduct assessments of landslide susceptibility and hazards in selected urban areas and high-volume transportation corridors.

Measures: Number of risk/hazard assessments delivered to customers. Number of jurisdictions that have adopted improved land-use plans and emergency response plans or other hazard mitigation measures based on USGS landslide hazard information.

Partners: USDA Forest Service, US Fish and Wildlife Service, Environmental Protection Agency, FEMA, California county flood control districts, Ventura County, California, National Park Service, California Geological Survey, Seattle, Washington, Kitsap County Washington, Washington Division of Geology and Earth Resources (WDGER), University of Washington, Puget Sound LIDAR Consortium, Portland, OR, Oregon Department of Geology and Mineral Industries (DOGAMI), Counties in Western Oregon, Portland State University, Colorado School of Mines, Hawaii Department of Natural Resources, California Geological Survey, Yosemite National Park, USGS National Earthquake Hazards, Land Remote Sensing, Geographic Analysis and Monitoring, and National Cooperative Geologic Mapping Programs.

Active Landslide Monitoring and Modeling

Conduct remote and near-real-time monitoring of active landslides and unstable slopes directed at improving public safety and improving understanding of landslide initiation and velocity. Cooperate with NOAA/NWS, the USGS Earthquake Hazards and Volcano Hazards Programs, NPS, and other Federal, State, and local agencies to monitor external conditions that can trigger landslides. Conduct research, including modeling and analysis, to improve understanding of landslide triggering mechanisms and premonitory behaviors that can aid in forecasting landslide initiation, enlargement, or reactivation. Continue development of physically based models for predicting and forecasting landslide location, initiation, and effects. The LHP plans to add monitoring sites in western Oregon in support of cooperative landslide studies with DOGAMI.

Measures: Number of areas or locations for which geophysical models exist that are used to interpret monitoring networks.

Partners: NOAA/NWS, USDA. Forest Service, Seattle, Washington, California and Washington Departments of Transportation, Counties in Western Oregon, USGS Water Resources Science Centers, Burlington Northern Santa Fe Railway, DOGAMI, WDGER, USGS Volcano Hazards Program—Cascades Volcano Observatory, Colorado Geological Survey, Colorado Department of Transportation, Colorado School of Mines, and Fremont, California.

Rapid Post-Landslide Hazard Event Assessments

Develop probabilistic and deterministic models and methods, including rainfall thresholds, for forecasting initiation of landslides in response to weather-related events. In cooperation with the NWS, develop systems, algorithms, protocols, and procedures for rapidly processing incoming data, making forecasts, and notifying partners and other users of forecasts. These systems and algorithms, such as simple rainfall accumulation/duration threshold models, can be evaluated and enhanced by using data from existing real-time rainfall station networks operated by USGS Science Centers in mountainous areas where landslides are common during heavy rainfall. State and local partners in this effort would be local NWS forecast offices and State emergency agencies. Conduct post-disaster reconnaissance and investigations to collect critical data needed to develop new or improve existing rainfall thresholds, landslide susceptibility and hazard maps, and similar products. Conduct rapid post-fire assessments of burn severity and of debris flow potential in cooperation with FEMA, federal land management agencies, state/county emergency management agencies, and other USGS programs.

Define rainfall intensity-duration threshold conditions that can lead to debris-flow activity from recently burned basins in southern California. In cooperation with NWS, incorporate thresholds into proto-type debris flow warning system for recent fires in southern California. Expand the USGS/NWS debris flow warning system to other parts of the US beginning with the Appalachian mountain region where LHP scientists are continuing to refine rainfall thresholds and where rainfall thresholds serve as the basis for landslide hazard advisories during hurricanes and severe storms. Also in cooperation with DOGAMI and the Oregon Department of Forestry, develop improved rainfall intensity-duration thresholds for western Oregon.

Measures: Number of areas or locations for which geophysical models exist that are used to interpret monitoring data.

Partners: NOAA, NASA, USDAFS, NPS, FEMA, Oregon Department of Forestry, DOGAMI, Seattle Department of Public Utilities, selected counties in southern California, Seattle, Washington, counties in Western Oregon, USGS Science Centers.

Communication and Mitigation

Continue to provide landslide information to Federal, State, and local government agencies, private industry, land-use planners, those who oversee environmental impacts of land development and formulate land-use policy, and private citizens. Conduct studies on the effectiveness of landslide information in achieving mitigation and use results to make improvements in the delivery of information to achieve mitigation goals. Continue to compile data about landslide-related losses and availability of landslide mapping and inventories across the U.S.

Measures: Number of responses to inquiries from the public, educators, and public officials to the National Landslide Information Center on hazard mitigation, preparedness, and avoidance strategies for landslide hazards. Number of formal workshops or training provided to customers.

Partners: American Planning Association (APA), International Landslides Consortium, Hawaii, Seattle and Kitsap County, Washington, Portland, Oregon and other jurisdictions in Oregon, and the Center for Disease Control and Prevention.
In addition, to the goals in Table 1, we will continue to respond to the approximately 1600 telephone and email inquiries for landslide information received annually.

Table 1 – LHP Outcome Measures for Fiscal Years 2005-2010

Fiscal Year measure completed	Geophysical Models	Hazard or Risk Assessments delivered	Workshops	Entities adopting new landslide mitigation measures
2005		Little Mill Campground (USFS), UT rock-fall hazard assessment	Seattle, WA	Logan Cave NWR, AR (USFWS) State of Hawaii adopting USGS Rock-Fall Hazard assessment method. USPS for southern CA used landslide advisory in Jan 2005 to adjust routes. USGS scientists participated in the Landslide task force at FEMA's disaster field office in Pasadena, CA. Ventura County, CA used USGS information about the La Conchita landslide to evacuate residents during February 2005 storm.
2006	Rainfall threshold, Seattle, WA Rainfall intensity-duration threshold s for recently burned basins in so CA that can be incorporated into a debris-flow	Seattle, WA landslide hazard map	USDA Forest Service training on use of models for assessing post-fire debris flow hazards from recently burned basins in the intermountain west	Little Mill Campground (USFS), UT 4 local governments in WA

Fiscal Year measure completed	Geophysical Models	Hazard or Risk Assessments delivered	Workshops	Entities adopting new landslide mitigation measures
	warning system (with NWS) for recent fires in so CA			
2007		Kitsap County, WA (LIDAR landslide map) Models for estimating volumes of material that can be produced from recently burned basins in so CA for unspecified risk assessment. Punta Gorda region, Ventura County, CA (Models for assessing landslide hazards) Segments of the Appalachians in North Carolina (Improved rainfall thresholds.)	Kitsap County, WA So CA Ventura County, CA	1 unit or district on public lands[1] 4 local governments in WA, OR or southern CA Landslide hazard assessment developed by LHP to be provided for use to Ventura County, CA
2008		Portland, OR (landslide susceptibility or hazard	Oregon	1 unit or district on public lands 4 local governments in Oregon,

[1]The LHP responds regularly to requests (averaging 1-2 annually) for technical assistance from various national parks, monuments, wildlife refuges, ranger districts, and similar entities on public lands and the information is generally used for making decisions related to landside mitigation.

Fiscal Year measure completed	Geophysical Models	Hazard or Risk Assessments delivered	Workshops	Entities adopting new landslide mitigation measures
		map for West Hills.) Models for estimating the probability of debris-flow production from basins recently burned by wildfire in so CA for unspecified risk assessment		or southern CA
2009	Rainfall Thresholds for Western Oregon	Area of Western Oregon, to be determined Decision Support system that will be used to assess post-wildfire debris flow hazards and direct mitigation approaches in basins recently burned by wildfire in so CA. 2 unspecified risk assessment of basins recently burned by wildfire in so CA	Oregon	1 unit or district on public lands Oregon Departments of Forestry, and Transportation (rainfall thresholds) 2 local governments in Oregon or southern California
2010		Area of Western Oregon to be determined	Oregon	1 unit or district on public lands 4 local governments in Oregon or southern California

Partners and Customers

Many different Federal, State, and local agencies are now involved in landslide research and mitigation in the U.S. The National Landslide Hazard Mitigation Strategy was prepared on behalf of this large multi-sector, multi-agency stakeholder group involved in landslide hazard research and mitigation. Although the Strategy is national in scope, it is not exclusively for the Federal government or for other levels of government. Mitigation occurs at the State and local levels, and the foundation of the Strategy is the development of partnerships with many stakeholders, at all levels of government, the private sector, and the general public.

Because the need for information spans the interests of many public and private organizations, the national strategy offers opportunities for mutually advantageous partnerships relating, for example, hazard assessments, monitoring, and emergency response and recovery of public assets and transportation systems.

Planners and other public officials working at the city, town, state and regional levels are confronted daily with the potential for landslide hazards, and they need scientific information so that they can make informed decisions about hazard reduction and land-use policy. Federal agencies involved with land management and hazards response that would use products and information developed by LHP are as follows: the USDAFS, Bureau of Land Management, Bureau of Reclamation, NOAA, U.S. Army Corps of Engineers, National Park Service, Federal Emergency Management Agency, U.S Fish and Wildlife Service, and the U.S. Department of Defense. Landslide hazard information would be of particular use to State geologists and State geological surveys. State and local disaster and emergency management offices and fire suppression managers, as well as individuals and private engineers, geologists, and planners represented by the American Society of Civil Engineers (ASCE), Association of Engineering Geologists (AEG) and APA, increasingly rely on USGS web pages, both during emergencies and when making decisions about how to respond to hazards and emergencies. These organizations also rely on USGS hazards information in making long-term decisions about their personal and economic lives.

In addition, the USGS directly or indirectly funds and maintains landslide hazard expertise in several of its other programs (Volcano Hazards Program, National Cooperative Geologic Mapping Program, Earthquake Hazards Program, the Coastal and Marine Geology Program, and the Water Resources and Geography Disciplines). These programs direct research and assessment of landslides, debris flows, and lahars caused by storms, earthquakes, wildfire, volcanoes, submarine landslides, and riverine and coastal erosion.

Program review

The LHP updates its 5-year plan every 5 years or more frequently if necessary. Revision of the program's 5-year plan is led by the program coordinator with input from project chiefs, team chief scientists, and landslide experts from one of the following: State geological surveys, universities, and private industry. The final plan is reviewed within the USGS and externally.

The LHP follows the long-established Geology Discipline's process for reviewing new and existing projects. The procedure is as follows. The Geology Discipline issues an annual call for workplans called the Geology Annual Science Plan containing scientific and funding guidance for projects. The Geology Annual Science Plan is derived from the USGS Director's Annual Guidance and the program's 5-year plan. Scientists submit annual project s to the Geology Discipline for LHP's review, which includes an examination of the strengths and weaknesses in staff, scientific methodology, progress on goals, and use of funds. This review of new and continuing projects is conducted by scientific peers from the LHP, other disciplines in USGS, and other organizations. LHP review may also solicit stakeholder review depending on the nature of the project.

National Research Council Review

In 2003 the NRC of the National Academy of Science completed a review of the National Landslide Mitigation Strategy proposed by the LHP at the request of Congress. The task of the NRC was as follows:

> In response to a request from the U.S. Geological Survey, an ad hoc committee established under the auspices of the Board on Earth Sciences and Resources will provide advice regarding the optimum approaches and strategies that could be applied to implement federal-state-local private partnerships to mitigate the effects of landslides and other ground failures. The study committee will:
>
> - Assess the approach described in USGS Open-file Report (00-450 National Landslide Hazards Mitigation Strategy), comment on the federal-state-local-private partnership concept described in that report, and evaluate whether all the appropriate partners that should be involved in a national landslide hazard mitigation strategy are identified. This assessment should be provided in the form of a brief interim report.
>
> - Consider the potential roles for each of the federal, state, local, and private sectors, and provide advice regarding implementation and funding strategies to stimulate productive, effective, coordinated partnerships.

As part of its analysis, the committee will provide an overview of research priorities required to support the activities of each sector.

The NRC commended the USGS for undertaking the initial steps toward a comprehensive national landslide hazards mitigation strategy and recommended increased funding for the LHP. (See Appendix B for the executive summary of the NRC report entitled, "Partnerships for Reducing Landslide Risk: Assessment of the National Landslide Hazards Mitigation Strategy.")

Expertise and Capabilities

As of 2005, the LHP has a scientific staff consisting of 17 geologists, engineers, hydrologists, physical scientists, geographers and land-use planners who have expertise in a broad range of landslide types and processes. LHP scientists have experience in applying field, experimental, and theoretical techniques to landslide research, real-time monitoring, and hazard assessments. One position, a geographer, is devoted to public education and outreach through the National Landslide Information Center. The LHP also has a small support staff that assists with field instrumentation and monitoring, GIS applications, publication, and web-site development and maintenance. A part-time program coordinator and full-time associate program coordinator at USGS headquarters manage and promote the LHP.

In addition to its personnel resources, the program currently maintains several field monitoring sites, an instrumentation laboratory stocked with tools, sensors and data collection hardware, a set of geodetic-grade GPS receivers, and total-station surveying equipment. The LHP operates a geotechnical laboratory in cooperation with the Colorado School of Mines, Golden, Colorado.

Projected additions to workforce 2006-2010

LHP anticipates several retirements before 2010, and the LHP will need to hire additional staff to maintain the necessary expertise to continue its leadership in landslide hazards research, monitoring, and assessments, carry out the program's mission, and keep up with developments in technology.

1. Landslide researcher with expertise in numerical modeling to model infiltration, runoff, and erosion as they relate to landslide and debris-flow initiation in burned and unburned settings. Program 5-year goals supported by this position: Active Landslide Monitoring and Modeling, Landslide Hazard Assessments.
2. Landslide researcher to model debris-flow run out (e.g., volume, peak discharge, inundation area), and catastrophic slope failure (both earthquake and climatic induced). Program 5-year goals supported by this position: Active Landslide Monitoring and Modeling, Landslide

Hazard Assessments, Rapid Pre- and Post-Landslide Assessments.

3. Geotechnical engineer or engineering geologist to study the physical (mechanical & hydraulic) properties of soils and landslide materials relevant to landslide initiation and movement. Program 5-year goals supported by this position: Landslide Hazard Assessments.
4. Landslide specialist to develop and test rainfall thresholds and to develop automated systems to process incoming data and forecasts relative to rainfall thresholds to produce predictive maps for use in issuing landslide advisories/watches or warnings. Program 5-year goals supported by this position: Rapid Pre- and Post-Landslide Assessments.
5. Technician with expertise in real-time landslide monitoring systems and telemetry (including satellite-IP telemetry) to install, operate, improve, and maintain LHP landslide monitoring sites. Program 5-year goals supported by this position: Active Landslide Monitoring and Modeling.
6. Landslide specialist to apply modern remote sensing methods such as analysis of burn severity from Landsat and topographic characterization from INSAR and LIDAR to detecting/mapping landslides. Program 5-year goals supported by this position: Landslide Hazard Assessments, Rapid Pre- and Post-Landslide Assessments.
7. Landslide specialist to document major landslide events and compile/maintain a landslide database for use in developing rainfall thresholds and developing maps of landslide initiation, transport and deposition zones. Program 5-year goals supported by this position: Rapid Pre- and Post-Landslide Assessments.
8. The landslide program also requires a small number of junior scientist or student positions to support project activities including field work and maintenance of the LHP's growing GIS, remote sensing, and monitoring databases. Program 5-year goals supported by these positions: Landslide Hazard Assessments,
9. Active Landslide Monitoring and Modeling, Rapid Pre- and Post-Landslide Assessments, Communication and Mitigation.

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